A SYSTEM

OF

FAMILIAR PHILOSOPHY.

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OF

FAMILIAR PHILOSOPHY:

IN

TWELVE LECTURES,

BEING THE COURSE USUALLY READ BY

MR. A. WALKER.

CONTAINING

THE ELEMENTS AND THE PRACTICAL USES TO BE DRAWN FROM THE CHEMICAL PROPERTIES OF MATTER; THE PRINCIPLES AND APPLICATION OF MECHANICS; OF HYDROSTATICS; OF HYDRAULICS; OF PNEUMATICS; OF MAGNETISM; OF ELECTRICITY; OF OPTICS; AND OF ASTRONOMY.

INCLUDING EVERY MATERIAL MODERN DISCOVERY AND IMPROVEMENT TO THE PRESENT TIME.

Illustrated by Forty-seven Copper-plates, neatly and accurately Engraved.

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G.R. III.

PREFACE.

INSTINCT is the voice of God; it directs our first motions to feel, see, hear, taste, and smell, every thing that comes in our way. Here begins the first chapter of experimental philosophy: here is laid the corner stone for our knowledge of Nature and her laws; for at a time when a nurse supposes a child is only amusing itself by striving to catch hold of every thing within and without its reach, it is laying in a stock of important information! By this propensity, we learn to know distances, hardness, softness, painful and pleasurable objects, heat, cold, and many other qualities of bodies, long before it is suspected by the unobserving part of mankind. Curiosity being thus natural to the soul of man, we are solicitous after

every species of information; and it would be extremely unnatural to suppose we should be less inquisitive, less solicitous after the most important of truths—I mean the knowledge of Nature and her laws; for it can scarcely be thought possible that any rational creature can be unconcerned to know the state of the world about him, or to behold the various phænomena that perpetually obtrude themselves upon the senses, without being strongly prompted to enquire into their cause and nature. And though philosophy has of late been branded as the cause of mischief by those whose interest it is to promote ignorance and slavery in the world; the wise and virtuous know well that there is no enquiry whatsoever more calculated to inspire every good disposition of the heart, and every useful acquirement of the head; that points out a more rational path to a knowledge of the Deity, or more rationally weans the mind from narrow and confining prejudices. In the following Lectures, Nature has been set to work in variety of ways, to prove the truth of her own operations; and no assent has been asked to a single proposition, that was

not fairly and openly proved by experiment or observation: for our present philosophy but points out the means of interrogating Nature in the way of trial and experiment. This, however, is what gives it the superiority over that of the ancients; for their systems of philosophy were built so much upon hypothesis and conjecture, that one system has given way to another in such succession, that many suppose ours shall give way in due time, and be swallowed up in the tide of opinion. But if the approach to truth by the way of analysis be slow, it is sure: facts command conviction; and, to the glory of our own times, fanciful conjectures fly before experiment, like shadows before the sun. Truth, indeed, is a difficult acquisition. We find it matter of circumspection to set down any thing as such even in our most ordinary affairs; but much more so when we dare to investigate Nature; we must see her on all sides, or it will be more than probable we shall deceive ourselves. Pythagoras is said to have been so conscious of the difficulty of truth, that he would not suffer himself to be called one of the

Magi (one of those ostentatious names which the learned of his time took upon them)---No, said he, I am but a philosopher, that is to say, I am a lover of, and an enquirer into, truth, rather than one really possessed of it. Like him, the science and its professors affect the same modesty, as knowing, that when we have stretched our faculties to the utmost pitch, we know but little in comparison of the immensity that lies beyond our reach. Yet, nevertheless, though our scanty enquiries are confined to short limits, and though we can but see and reflect upon the ways of Nature imperfectly; it gives an high, it gives a rational delight to the mind even to be lost in such excursions; for they teach us to be humble, they teach us to be wise; they teach us to be modest concerning our own abilities, and to pay a suitable adoration to that Being who sits at the head of these things.

A beautiful writer observes, that the universe may be compared to a book written with sublime obscurity! where the author, seeming to level him-

self to the capacity of his readers, almost persuades them they nearly understand the whole. Happy for us who enter this labyrinth, if we do not mistake the path! Much has been done in these latter ages for the progress of the human mind, but little for our ſpecies; much for the glory of man, something for his liberty, but not much for his happiness. In a few directions our eyes are dazzled with a promising light; but thick darkness still covers an immense horizon. The mind of the philosopher exults with satisfaction upon a small number of objects; but a view of the stupidity, the slavery, the extravagance, and the barbarity of man, takes off much from that satisfaction. The friend of humanity can scarcely receive unmixed pleasure, but by abandoning himself to the endearing hope of the future.

It is, however, a pleasing solace to the studious mind, that the great, the liberal, the generous purpose of philosophy, is an attempt to let mankind see what Nature is, that they may judge between

her works, and the extraneous systems of art and police. It is the business of the teacher in philosophy (in order that it may have its moral effect), that he have nothing to do with the bitterness of satire, or the enchantments of the theatre: neither the thunder of eloquence, nor the sublime of inspiration, should enter into his disquisitions: he should confine himself to the simplicity of reason: he should open the book of Nature before his readers; this speaks an intelligible language to all understandings. He should shew that the foundation of morality is in the constitution of things: he should *suppose* nothing; but endeavour to *prove* all he inculcates.

In the following work I have endeavoured to follow up these ideas, many of which are not my own: I have borrowed liberally, not only the doctrine, but in many instances the very words of various authors and experimentalists, where I found them more intelligible, or better, than any I could substitute in their place.

But having been much used to arrangement, in order to render my oral lectures plain and simple, I hope the reader will find the attention paid to that circumstance in the following sheets contribute to the easy apprehension of the system and unity attempted in them. The work having been written at various times, and in various places, tautology has crept into many parts of it; and I fear some are more condensed than they should be in a system of familiar philosophy. Originality, or the pride of discovery, has not led me beyond the bounds of what I believe to be truth. The identity of fire, light, heat, caloric, phlogiston, and electricity, or rather their being but modifications of one and the same principle, as well as their being the grand agents in the order of nature; these are the leading problems of the work; and the parts which have, in a great measure, any pretensions to novelty. Whether I am right or wrong in my ideas of them, I doubt not but they will have a fair and candid reading. The theory was not sought, but has obtruded itself through an experience of near forty years;

and though it differs in many points from the late received and adopted system of chemistry, my admiration of that simple and elegant system is not at all diminished: I rather lament that its worthy and ingenious founder did not live to have perfected so excellent and promising a beginning. It may appear bold, invidious, or like the affectation of singularity, to differ from doctrines that are become established throughout Europe: but I dare do this, and more, when truth is the object. If my opinions are confuted by experiment and reason, I will bow to conviction, and be one of the first to abandon my theory. I solace myself, however, with the idea, that in an honest and laborious search after truth, right or wrong, nothing is lost; and probably something may be gained. So comes this work into the world, without a string of capital letters attached to the name of its author. These fortuitous advantages, however, have too little connection with a work of this nature to affect those whose good opinion alone I am solicitous to obtain. Like others, no doubt, it will be singed a little in its passage through the ordeal of criticism; for

polished writing is neither in my power, nor do I think it proper upon a didactic subject like this. A simple perspicuity has been my aim ; and to be easily understood my earnest endeavour. The plates, though not elegant, will, I trust, be fully explanatory of my meaning : and a copious index will not only point out every subject, but the particular parts of each, so that they may be instantly found. This index is also made a dictionary of such uncommon words as could not, without affectation, be omitted in a work of this nature.

ERRATA.

PAGE 16, l. 13, *for* Fig. 14, *see* bottom, right hand corner, of Plate 2, in Magnetism
—— 74, l. 3 from the bottom, *for* the tower *s a*, *read* the tower *s a*, Fig. 14.
—— 76, l. 7 from the bottom, *for* two parallel wires, *read* two diverging wires.
—— 226, *for* fire, gunpowder, *read* fire gunpowder.

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INTRODUCTORY LECTURE,

CONTAINING

SOME GENERAL IDEAS

RESPECTING THE

SYSTEM OF NATURE.

SECTION I.

IN order to explain any art or science, I think it is useful to give some outlines, or general ideas, of their principles, before particular parts are entered upon. On this account, a very unpopular beginning will be given to this work: The philosopher will find some documents to condemn, and some perhaps to wonder at; the student will be perplexed before he is instructed; and the critic will have plenty of matter for animadversion, and perhaps for ridicule. But as I shall advance nothing but what I believe to be true, and hope to demonstrate, it will promote the cause of truth should any part be confuted.

I ſet out with a persuasion, that attraction and repulsion are the great acting principles of the universe. By attraction, I mean that tendency which the atoms of matter have to unite and form

bodies; and by repulsion, the reaction of fire, in its combined, active, and latent states; or in its character of electricity, heat, or light. The experiments, through the course of this work, will principally tend to the establishment of this persuasion.

I conceive the Sun to be the fountain-head of fire in our system; and that his light, when it reaches the earth, is only that fire in a greatly rarified and mixed state; and therefore, when condensed by lenses or mirrors, it becomes real fire again. That light is matter, or material, cannot be doubted when we observe the inflections it suffers in passing out of one medium into another, as out of air into glass, or out of glass into water, &c. which ſhews that it is subject to the same sort of attractions and repulsions as the grossest matter, and, therefore, is matter itself. That the particles of light repel each other, and fill all space, in a more or less diluted state; that they are thrown off, or repelled from the equatorial parts of revolving suns, and recruited by receiving or imbibing light at their polar parts, from other suns; therefore, that light exists in the absence of the luminous body, and is only put into progressive motion by it. That (by what will be made probable hereafter), it proceeds from the Sun, elementary, or in the character of electricity; but being obstructed in its passage through an ill-conducting atmosphere, it mixes with the air and becomes light; and what reaches the earth, unites with bodies on the earth's surface, and becomes culinary fire. We have no conception for what purpose the sun turns on his axis, if it be not to increase this repulsion and momentum, by throwing off those particles of light centrifugally from his body, as Plate I, by which they are projected into infinite space in a more and more diluted state, till meeting with light from other suns of greater momentum, they mix, unite, and

are turned into the stronger stream. For we shall prove the fixed stars to be suns; that they turn on their axes like ours; and no doubt project their light in the same way. See Plate II. fig. 1. So these luminaries, dispersed through space at infinite distances from one another, fill the universe with light of various colours; some projecting a predominance of red, others of blue, and others of white, light. From the great distance by which they are separated, the light of each must become feeble before it reaches its nearest neighbour; and not only be absorbed into the stronger stream, but much of it attracted into the body of that neighbour, at its polar parts. For the polar parts of each sun, having little or no centrifugal repulsion, its attraction in those parts will draw in vagrant and weak light from other suns, and thereby supply continually the quantity thrown off at its equatorial parts. This idea may be rendered more familiar by Fig. 2, where *a a* represents the projected light of the sun *S*, and *c c* its absorbed light. Hence no waste or diminution of light or heat has been observed in our sun; or in the light of those other suns, the fixed stars. By thus giving and taking, the whole universe is filled with light and motion! For, that a feeble light is capable of being absorbed, turned back, or retarded, in its motion, by stronger light, is evident from the light of the stars being lost in the superior splendour of the sun: and from the feeble light of a common fire being put out, by the light of the sun. This effect, though so common, may not, perhaps, have been accounted for on the above principles. We will therefore familiarize it by Fig. 3, where *S*, the sun, darts his rays in the fire *F*. Many other examples will occur in the course of this work.

As the sun turns on an axis that inclines but 8° from crossing

the ecliptic perpendicularly, his equatorial, or greatest centrifugal discharge of particles, will be nearly in the zodiac, or track of the planets. May not the planets be turned on their axes by this impulse of light? I know that this ſuggestion ſeems like an attempt to revive the exploded vortices of Des Cartes: but this is not the case; his vortex was made in an imaginary subtil matter, the existence of which could never be proved. Light can be proved to be real matter; to have motion, and, of course, a momentum. Suppose *S* the sun, and *E* the earth, Fig. 4, and that the lines *a b c d*, &c. represent rays of light issuing centrifugally from the sun. A line from the sun's centre of gravity *s*, to that of the earth *o*, will shew the direction in which the two bodies mutually attract each other; or the line in which they would fall together, if no counteracting principle prevented it: that counteracting principle, I hope to prove, is light. The equal distances of the lines which represent the rays, being agreeable to the equable distribution of light through the zodiac, it may be seen that twice the quantity falls on one side of the line of direction *s o*, as on the other, viz. *a b c* and *d*; while *e* and *f* fall only on the contrary side of the line of direction. Though this is an exaggerated proportion, yet in all the positions in which the earth stands to the sun, during its annual revolution round him, it will be found that more rays fall on one side of its axle and centre, than on the other. If a ball, therefore, suspended in infinite space, without friction, or resistance to motion, have a greater impulse on one side than the other, it must turn on its axis. It is true the momentum, or moving force, of light, has been found to be so small, as to seem inadequate to such an effect. A small wire balance, nicely suspended on a point, having a square inch of thin latten fixed at one end, was covered by the receiver *c*, Fig. 9, it was a little more than counterbalanced by a small shot,

which rested on the projected plane *a*. The focus of a lens fourteen inches diameter, and twenty-six inches focus, being directed upon it, the balance was instantly put in motion, and the shot lifted from the plane. The receiver being close, *this* could not arise from the motion of heated air: but lest that should have been the case, I had the air exhausted on the air-pump, and on applying the lens as before, the effect was the same. I then balanced one hundred pieces of horse-hair, each piece of the same length, on a nice beam, with one grain: one of these hairs lifted the shot: so that the impetus of light on one and a quarter square foot of the earth's surface, may be considered as equal to one-hundredth of a grain; and by calculation equal to twenty tons on the whole disk of the earth. Mr. Mitchel, indeed, made the same experiment, with great care and address, with a concave mirror of three square feet furface, and calculates the momentum of light on a square foot of the earth's surface to be no more than the one thousand eight hundred millionth of a grain. The experiment in both cases is of too delicate a nature to draw any decisive conclusion from, except that light certainly has a momentum or moving force.

If light, concentrated in the focus of a large burning-glass, can put a small balance into motion, or move a needle suspended by a magnet; or influence the tail of a comet, so as to force it always opposite the sun; and what is still more, make a pellicle of gold, molten in the focus of a large lens, turn on its axis, the same way with the earth's diurnal motion, all the time the focus is kept upon it (ſee Optics): May not its aggregate momentum be a balance to the earth's gravity towards the sun? and may it not be natural to suppose the earth's distance from the sun was determined by the

balance of those two powers? analogous to bodies on the earth, which have their tendency to absolute solidity, counteracted by the repulsive power of light or fire, with which every body on the earth's surface is more or less united? But this is not all. If the impulse of light be greater, on one half of the earth, than on the other, may not this also account for its annual motion round the sun, to produce the seasons? To prove that a diurnal motion, similar to that of the earth, may be produced by a centrifugal stream of air, I fixed in a circular box the arms *a b c*, &c. Fig. 5, turning on the centre *n*; these arms were of thin boards, and the box was close, except at the holes *s s* to let the air in, and at the funnel *g* to let it out. A thin glass globe was hung by its centre *m* perpendicularly to the machine, by a fine thread. The arms being now turned swiftly round by the handle *r*, a current of air flows through the funnel *g*, and the globe begins to turn round without being pushed away. This I consider as similar in one fluid to what it may be in another; and a power capable of producing a circular motion. But to give the ball both diurnal and annual motion, by a centrifugal current of air, I made the circular wooden box, Fig. 6, with oblique holes through its side. This box being close at top and bottom, there was only the hole *a* to admit the mouth of a double-bellows to make the current of air equal. The glass ball was hung by a very long thread, exactly over the centre *a*; this gave it a constant tendency towards that centre, naturally representing the gravitation of planets towards the sun. The ball being now placed by the side of the box, and the bellows blown, the ball instantly began to turn on its axis, and describe an oval circuit round the box. This oval circuit was more than I expected, so I had the oblique holes bored very true, suspecting that an inequality in them might occasion this inequality in the circuit;

still it was oval. Considering that the sun's axis inclined 8° from a perpendicular to the plane of the ecliptic, it was evident, that if solar impulse was the cause of the earth's annual and diurnal motion, it must be less in one part of the earth's circuit than another, and of course produce an oval rather than a circular motion. I had the plane of the ball's orbit inclined 23½ degrees to the level of the box, and still the oval circuit was invariably produced, as it is in nature, viz. at the place where the solar stream must be most powerful, i. e. when the earth is in the middle of it, near the time of the solstices; for the plane of the sun's equator cuts the ecliptic about the eighth degree of cancer, and the eighth degree of capricorn: and near these were the aphelion and perihelion of the ball, or its farthest and nearest distance from the repelling box. It may seem, that as the ball passes the middle of this stream twice in one circuit, it should have two distant and two near approaches to the repulsive box. No: it still describes equal areas in equal times, and conforms to the law discovered by Kepler, that a two-fold projectile force balances a four-fold power of gravity. In Fig. 8, this idea may be made more intelligible. Let *S* be the sun in one of the foci of the earth's oval orbit *A B*, with a rotation conceived on his axis, from east to west, in twenty-five days; and on an axis inclined 8° from a perpendicular to the plane of the ecliptic: this axis, inclining towards the tenth degree of libra, or towards the point *r*; all which is agreeable to observation: the plane of the sun's equator, therefore, will cross the plane of the ecliptic, near the perihelion and aphelion of the earth's orbit; or in other words, in those two parts of the orbit which are the nearest and farthest from the sun, as *s* and *u*, for these two points are not at *t*, where the sun enters ♑ at mid-winter; or at *w*, where the sun enters ♋ at mid-summer; for the earth is not come to its

nearest distance from the sun on the 21st December, nor to its greatest distance on the 21st June, but about eight or nine days later. The earth, therefore, crossing the solar stream at those two critical places, viz. at *s* and *u*, muſt have its orbit and motion affected by it. The manner in which the plane of the sun's equator crosses the ecliptic, may be better understood by inspecting Fig. 7, where *s s* represents the plane of the ecliptic, and *u u* a plane passing through the sun's equator; so *t* may represent the sun's axis, and the angle of 8° it makes with a perpendicular to the ecliptic *n*. By a section of this stream, as Fig. 2, a clearer idea of this hypothesis may be conceived; where the planet *a* is in the middle of the sun's equatorial stream, and of course impelled to its aphelion or greatest distance. But in the situation *c*, it is but partially immersed in it; here the sun's attraction will, in a degree, overcome the repulsion of light, and draw the planet to its perihelion or nearest distance.

The zodiacal lights seen at the solstices are also a proof that the earth crosses a stream of more than usual light, at those times; and as all the planets move in this equatorial stream more or less, may not their distances, motions, and eccentricities, be thence accounted for? The earth moves the swiftest when it crosses the stream at the winter solstice, and gradually slower and slower, till it reaches the summer solstice; soon after which, it again crosses the stream, but from its greater distance from the sun, and the slowness of its motion, an accession of inertia or retardation has taken place, that is not easily overcome by an increasing impulse. The stream also is weaker, as being farther from the sun than at the winter solstice. Hence the effect of this transit accelerates the motion of the earth but slowly: but aided by

the increasing power of gravity, as it approaches the autumnal equinox, it acquires the acceleration necessary to make a two-fold power of centrifugal tendency to balance, or rather overcome, a four-fold increase of gravity. Appealing to the fact in nature, and as may be seen described in any ephemeris, this acceleration and retardation is perfectly agreeable to the motion of the earth, and to that of the other planets, viz. that they describe equal areas in equal times, Fig. 8, for all the spaces *a b c d*, &c. are equal to one another; the earth travelling from *o* to *p* in January, and only from *q* to *z*, in the same space of time, in June. But if a thread could be carried with it, whose end was fixed at the sun's centre, it would pass over the same quantity of space, in the same time, in all parts of the orbit. This is not matter of conjecture, it is confirmed by the most accurate observations, and noted in the Ephemeris, for every six days throughout the year, for many years past and to come. In Fig. 8, it is only noted for the beginning of every month, viz. that the semidiameter of the sun on the first of January, as measured by a good micrometer, is 16′. 19″, 2; but on the first of July, it is only 15′. 46″, 9. Why appears the sun less in July than January? All objects diminish in perspective, as we recede farther from them; and we are nearly one-thirtieth of the sun's mean distance from the earth nearer to him in January than in July. The hourly motion of the earth, in its orbit on the first of January, is 2′. 32″, 9; on the first of July it is only 2′. 23″, see Fig. 8. Why does the earth move faster in January than in July? Because its near approach to the sun increases its velocity; and it is also in the middle of the zodiacal stream at that time.

SECTION II.

On the Influence of the Sun's Motion on the Earth and Planets.

IT may seem a little contradictory that the sun should both attract and repel. I conceive the light of the sun to be merely his atmosphere; an ocean of fluid fire that surrounds him, whose particles repel each other, and are the cause of repellency and elasticity in all other matter. But the body of the sun attracts like all other bodies, is a solid nucleus, perhaps black, and covered but thinly with his repulsive atmosphere; insomuch, that, by great emission, some parts of that body may be left bare, and cause those black spots so frequently seen on his face. Those spots have always a dusky shade round them, and appear hollow and indented when they pass over the edge of the sun; circumstances favourable to this opinion. By them we learn, that the sun turns on his axis in twenty-five of our days, and six hours. That this equatorial emanation from the sun must diminish in its force by distance (perhaps as the square of that distance) is probable, from the nearest of the planets; Mercury and Venus being thrown much farther out of the plane of the ecliptic than the superior planets, Mars, Jupiter, Saturn, and the Georgian planet. The inclination or greatest latitude of Mercury being $7^{D.}\ 0^{M.}\ 0^{S.}$

Venus - - -	3	23	35
Mars - - -	1	51	0
Jupiter - -	1	18	56
Saturn - - -	2	19	50
Georg. Sid. -	0	46	20

Now as the greatest distance, north or south, that any planet departs from the plane of the ecliptic, is not more than seven degrees, and as the sun's inclination to that plane is eight degrees, it follows, that all the planets of our system must be more or less immersed in his equatorial emanation; and that it is that stream that keeps them in their orbits. Not that we conceive, that it is only from his equatorial parts that light is projected; it must be also projected from the regions towards his poles, but certainly not with the same vigour. If a large hollow globe, perforated with numberless little holes, were filled with water, and turned swiftly round, water would fly from all parts of it, no doubt centrifugally; but, certainly, from its equatorial parts with the most force: so light comes to us from all parts of the sun, or otherwise he would not appear round. A pleasing representation of this attraction and repulsion may be made in a jet of water, Fig. 13, *b*, is the spouting pipe, and *a*, a small wooden ball immersed in the jet. This ball will turn on its axis like a planet, and preserve its situation for a long time, if the jet be equal: the jet representing the repulsive power of solar light; and the tendency which the ball has to fall, the influence of attraction. A ball was made oblate (or like an orange) to represent the earth and Jupiter; when it was immersed in the jet it immediately turned its protuberant side towards the stream, and revolved in that direction.

It is an excellent rule in philosophizing, to admit no more causes than what barely account for the phænomena. If in the course of this work it can be proved that light, fire, phlogiston, electricity, &c. are but modifications of one and the same principle, viz. light, the difficulties attendant on our researches into nature will be greatly reduced.

The materiality and momentum of light being proved, may not the motions and distances of both the planets and their satellites be rationally accounted for mechanically?

If, for instance, the planet Jupiter be made of materials specifically lighter than those of the earth (which the swiftness of his motion on his axis strongly indicates), his gravity towards the sun would be less, in proportion to his quantity of matter; and from his greater surface he would be more repulsed by the stream of light; and therefore those two powers would not balance each other, but at a much greater distance than the earth is from the sun. Saturn is also next to Jupiter in size, and therefore subject to great repulsion; from whence may arise his rapid rotation on his axis, and his still greater distance from the sun. The smaller planets are all nearer to the sun, and must have greater density and solidity to bear the heat incident to their situation; of course their gravity will combat a stronger repulsion; and they will be drawn nearer to the sun before the balance between those two powers will be effected.

Mars being our next neighbour, he has many coincidences with the earth; he turns on his axis in nearly the same time; that axis inclines like that of the earth; and his orbit crosses the solar stream near the same places with the earth. This last coincidence, probably, occasions the other two. As the materials of which he is formed appear to have a chemical rejection to red light (which seems the cause of his dusky red appearance), that part of light being the most powerful of any of the seven colours of which light consists, why may he not have so much more impulse from red light, in comparison of the green light, which our globe rejects, as

to make their diurnal motions nearly alike, and balance his greater distance? for Mars is situated one-third farther from the sun than the earth.

Treating here of general matters (to give an elementary idea of this hypothesis), the details and particulars must be postponed. The planet Jupiter revolves on an axis nearly perpendicular to the plane of the ecliptic; being therefore in a more diffused and diverging part of the stream of light than the inferior planets, both attraction and repulsion will act more equally upon his body than if he were nearer, and more exposed to the first impulses of the solar stream: hence his eccentricity is less, his motion more equal, and his oblate equatorial protuberance more immediately in a line with the two powers of attraction and repulsion, than that of any other planet.

The oblate protuberance of the earth lies oblique to the two influences, particularly at the solstices. Must not the solar impulse, therefore, be greater in summer on our northern hemisphere, than on the southern? and, in winter, greater on the southern, than the northern hemisphere? and thus force the earth's axis progressively more and more towards a perpendicular (as is well known to be the case) and produce the precession of the equinoxes? These effects may be better understood by an inspection of Fig. 12, where the southern hemisphere *s*, of the earth *c*, will be found more immersed in the solar stream than the northern: and in summer, when the earth is at *a*, the northern hemisphere *n*, will partake of both the influences, more than the southern. Must not these inequalities alter the position of the earth's axis, and make it recede farther and farther from its direction to the polar star, as is known to be

the fact? and if so, must not the plane of the earth's equator cut that of the ecliptic progressively more and more towards the west, in the contrary order of the signs, and, thereby, produce the precession of the equinoxial points?

As the impulse of light must be greater upon the earth and planets in perihelion than in aphelion, or at their nearest, than their greatest distance, of course the earth, by moving in its orbit slower in summer, will have its meridians come sooner to the sun every day, than in winter; and account for the nearer approach to equality of apparent and equated time in summer than in winter; which is also the fact.

These phænomena, I presume, may be as rationally accounted for by the theory of impulsive light, as from that of centripetal and centrifugal forces. For though, by both theories, the earth must move swifter in perihelion than in aphelion, the diurnal motion is not at all accounted for by the latter theory. Now if (as has been proved) there be a greater impulse on one side of the earth than on the other; and *that* also agrees with the way it actually revolves, viz. from the west to the east; and if the impulsive momentum is less in aphelion than in perihelion, it follows that, not only the earth's annual progress in the ecliptic must be retarded, but also its rotation on its axis. For, though the proportional difference between the impulse of light on one side and on the other, must be the same at whatever distance, yet the sum of the two impulses will be less at a greater, than at a smaller distance; and account for solar and sidereal time, being nearer equality in summer than in winter; and that the diurnal rotation is also somewhat slower.

These observations are advanced here only to give a general view of that important principle, light. But it must not be considered yet as in either an astronomical or optical point of view. These two subjects will be separately treated at large. We shall now consider light or fire in the various effects it produces, in uniting, forsaking, decomposing, or rarefying bodies, here on the earth.

SECTION III.

On Fire.

IN the order of nature we find opposing or antagonist principles in a state of perpetual warfare. The centrifugal tendency of the planets is said to be a contention with the centripetal force, that never ceases for a moment; for Nature never sleeps. The sun makes war upon the inertia of the earth; and in spite of its sluggish nature, makes it to bring forth trees, fruit, and flowers. Every animal muscle has its antagonist muscle: passion is checked by reason; and no two enemies are more inveterate than heat and cold, action and reaction, buoyancy and gravity, &c. &c. But of all opposing or antagonist principles, none exhibit so general an enmity as fire and attraction. These two enemies are in a state of unceasing warfare; attraction drawing the particles of matter into a closer and closer union; while fire (or caloric, in the language of modern chemistry) is still striving to set those particles more and

more at a distance. Hence it is said, that heat expands all bodies, and that cold contracts them; that is, cold assists attraction in overcoming the repulsive power of fire: for we do not consider cold as an agent or a body, it is but a name we give the absence or suppressed power of fire. Not that we consider fire as *totally* absent, or suppressed, even in the coldest bodies, for positive cold, or a total absence of fire, cannot be proved to exist in nature.

Whether fire, light, and electricity, are modifications of one and the same principle, will be considered hereafter; at present we shall only investigate its property of expanding all bodies it attacks, or is united with. 1st. An iron bolt that would easily pass through a ring, will stick fast in it after being heated a little in the fire. 2dly. If the bulb *a*, Fig. 14, be half filled with spirits of wine, tinged with cochineal, and grasped with a warm hand, the air *b* will swell and press the liquor up the tube *d*, so as to make it run out at *c*. 3dly. Quicksilver is peculiarly susceptible of expanding by heat and contracting by cold, and is therefore used for thermometers. *a*, Fig. 15, is a bulb blown at the end of a glass capillary tube, which is open at *b*; if the bulb *a*, be heated near to redness, the air will be so expanded as to leave the bulb *a* a vacuum; if then the end *b*, be dipt in quicksilver, the pressure of the atmosphere will force the quicksilver into the bulb, and fill both it and the tube *c*. If the bulb now be wet, and exposed in a frosty night, so that the water be frozen, the quicksilver will fall down the tube to *d*, which is called the *freezing point*, and where it must be so marked on its scale. The bulb is then exposed a few minutes in boiling water; this will make the mercury rise to *g*, where another scratch must be made on the scale, which is called the *boiling point*. We are now in possession of a scale for all the degrees of heat,

from ice to boiling water (for when water boils, no increase of fire can make it hotter in an open vessel). The space between *c* and *d* must now be divided into one hundred and eighty equal parts, and thirty-two more of the same divisions continued below the freezing point, if the tube will admit of it; so that *o* is extreme cold, thirty-two the freezing point, fifty-five temperate heat, seventy-six summer heat, ninety-eight blood heat, one hundred and twelve fever heat, at one hundred and seventy-six spirits boil, and at two hundred and twelve water boils. This is called Fahrenheit's scale, he being the inventor.

Fourth, The pyrometer is an instrument for measuring the proportional expansion of different metals by the same degree of heat. Bars of different metal, of the same length and thickness, are exposed in boiling water, fixed at one end, but operating on micrometers, or multiplying wheels, at the other, by which an index shews the proportional expansion between one metal and another.

1. White glass barometer tube - -	100
2. Hard steel - - - - - - - -	147
3. Iron - - - - - - - - - -	151
4. Copper - - - - - - - - -	204
5. Brass - - - - - - - - - -	232
6. Fine Pewter - - - - - - - -	274
7. Grain Tin - - - - - - - -	298
8. Lead - - - - - - - - - -	344
9. Zinc - - - - - - - - - -	353

So zinc has the greatest, and glass the least expansion, by the same degree of heat.

Fifth, *A* and *B*, Fig. 15, are two glass bulbs united by the tube *c*, and balanced on a point, *d*. This apparatus stands before a sheet-iron case that holds two hot heaters, *n* and *o*. In *A* is contained a red-tinged quantity of spirits of wine; and the space *B* is devoid of air, or a vacuum. When *A* is near the heater *n*, the liquor in it will be rarefied into steam, which rising to the top of the bulb, forms such a reaction on the surface of the fluid, as forces it up into the bulb *B*, which soon becomes heavier than *A*, and falls down to *o*; then are the spirits of wine forced up into *A* as before, and so on alternately, so as to produce all the force and action necessary to work two pumps, *r* and *s*. But the intention of the experiment is to shew the repulsive force of active fire; for *B* being lifted out of the power of the heater *o*, and *A* exposed to the action or heat of *n*, the two ends rise and fall alternately, becoming levers to work the pumps, *r* and *s*.

Sixth, The æolipile is another instrument to shew the repulsive power of fire; it is a large copper sphere, with a small tube (almost capillary) joining to it, see Fig. 16, at *a*. This vessel being a little heated, and its tube immersed in water, or spirits of wine, the pressure of the air will soon force the fluid into it. If then it be placed over the carriage fire *d*, the steam will be so violently forced out at *a*, as by the reaction given to it by the air, the whole carriage will be forced backwards in the direction *g h*.

Seventh, If a glass bulb, Fig. 17, be filled as above with spirits of wine, and inclined by the handle *b*, so that the spirits do not cover the end of the small pipe *d*, while a candle rarefies the spirit: if then the handle *b* is lifted up, so that the spirit covers the end of the pipe *d*, the fluid will be forced through the candle *c*, so as to

produce a cascade of fire, projected to a considerable distance. What is this, but the fluid rarefied into steam by heat, swelling, and thereby pressing the fluid through the pipe *d*?

SECTION IV.

On the repulsive Power of Fire.

THE sun acts upon the inert matter of our globe; and, by heating its surface, makes even blocks and stones swell by day, and contract by night. Its active fire, uniting itself to water, assists the rise of vapour, and replenishes the atmosphere with rain. Heat qualifies all menstruums to dissolve the matters to which they have affinity with additional powers:—salt, sugar, tea, resins, wax, &c. all dissolve in hot fluids, much easier than in cold. Fire is the most powerful agent in the decomposition of bodies. It is the only essential fluid in nature, and the cause of fluidity in other bodies, by separating their parts: for, as bodies become fluid by the application of fire, so fluids preserve their fluidity by the fire they contain. Hence even air itself might become solid, if deprived of the caloric, or fire, it contains; as bodies of the most difficult fusion become fluid, when penetrated by a sufficient quantity of the particles of fire. All bodies become hot, by the approach of ignited bodies and by friction: we find, however, that light, heat, and the electric fluid, have so many properties in common with fire, that we scruple

not to think, and hereafter hope to prove, they are all but modifications of the same principle. Rubbing, or friction, in *all* bodies, produces heat and electricity; and both these dilate bodies, help vegetation, germination, evaporation, motion of the blood, the growth of the fœtus, and the hatching of eggs. Heat and electricity both reduce and melt bodies; and bodies that receive heat with difficulty, receive electricity so, &c. Is it not more than probable, that the rays of the sun are diluted fire (nay, perhaps, electric fire)? May not the velocity with which they proceed from the sun, prevent their absorption by the air, in their passage through it? for perfectly transparent bodies receive no heat from solar light. And as all bodies have more or less affinity to fire, may not this diluted fire be absorbed by various bodies, and lie in union or a concrete form in them, till called forth from them by friction or combustion? Experiments that favour this hypothesis are, 1st. Rays collected in the focus of a burning glass, produce, on opaque bodies, the most intense heat that is producible by the art of man. 2d. Living vegetables imbibe light (as nutrition) from the air, and part with it back again into the air, in the act of combustion, boiling, or putrefaction (for rotten wood, putrid fish, the ignis fatuus, indeed all animal and vegetable substances, are luminous while decomposing by putrefaction); which is but parting with the inflammable principle, that was a constituent part of these bodies while in health. 3d. Bodies in the act of delivering fire to the air, or any other affinitive menstruum, are universally hot; hence the heat of a common fire, inflamed gunpowder, &c. The heat of effervescent mixtures, such as diluted vitriolic acid and iron filings —copper and diluted nitrous acid—iron filings, water, and sulphur, &c.

This principle (called caloric in the new language of chemistry), is the grand antagonist of the attraction of cohesion. These two opposing powers keep nature in a state of perpetual motion. When the attractive force is strongest, the body continues in a state of solidity; but if, on the contrary, heat has so far removed the particles of it, as to place them beyond the sphere of attraction, they lose their adhesion, and the body becomes fluid. Water, when cooled below 32° of Fahrenheit's thermometer, becomes solid, and is called ice. Above that temperature, its particles not being held together, it becomes liquid; but when raised to 212°, its particles give way to the repulsive power of fire, and flying off, assume an aëriform state: the same may be affirmed of all bodies in nature. But as no vessel can contain this subtile fluid, as it escapes through every thing, it is difficult to define it but by its effects: the pressure of the atmosphere checks it in part, and prevents fluids from flying off, in steam or gas, along with it. By surrounding bodies, and being interspersed among the particles of bodies (according as those particles are arranged or disposed by that polarity, which takes place when a body passes from a fluid into a solid state), the body is said to have a capacity for receiving, retaining, or parting with fire. When this repulsion overcomes the adhesion of fluids, and the pressure of the atmosphere, the fire flies off with the vapour, and the fluid is cooled; hence the cold, produced by evaporations of all kinds, ether, beer, &c. when in an exhausted receiver, sinks the thermometer. Spirits of wine boil in vacuo, by the heat of the hand, producing intense cold. Snow and sea-salt mixt, attract heat from neighbouring, or touching, bodies, producing ice in an hot room; and by Glauber and ammoniacal salt, with spirit of nitre, quicksilver may be frozen into a hard metal. Hence we see why fire, going into a latent state,

produces cold; and, into an active state, heat: why the blood, in an healthy state, retains the same heat in cold and hot weather. For evaporation cools both the earth and the human body.

SECTION V.

On latent Fire.

FIRE going into a latent state, may be represented as proceeding from a circumference to a centre, Fig. 18; or, as electricity passing out of a natural into a negative state. And fire going into an active, from a latent state, may be represented by *b*, as an emanation proceeding from a centre to a circumference, and also as electricity growing positive: for all bodies throwing out elementary fire are *hot*; absorbing it, *cold.*

Some things in nature have better capacities for receiving fire, uniting with it, or conducting it, than others. If I put the end of a rod of glass, and a rod of iron of the same length and thickness, together, into the fire, the iron, at its opposite end, will soon become too hot to hold, while the glass will betray no signs of heat. We say then that iron is a better conductor of heat than glass. 2d. I take a piece of iron in one hand, and a piece of wood in the other, the iron feels cold, and the wood warmer; I try their temperature by the thermometer, and find them both of the same heat!

How is this?—The iron has a strong affinity to fire, conducts the fire from my hand much swifter than the wood, and hence gives me a more lively sense of cold. 3d. I take up a warm poker in one hand, and the piece of wood in the other—the wood now feels colder, because my hands are warmer than the wood, and colder than the iron; the iron is, therefore, in the act of communicating an additional quantity of fire to my hand, and the wood depriving it of a portion of its natural quantity: for all nature strives at an equilibrium, while the great agents, fire and attraction, are continually at work to destroy or disturb it. 4th. Why do I clothe myself in wool?—Because it is a bad conductor of heat, and retards its escape from the body. I make myself a muff of fur, because it is still a worse conductor of heat than wool. For sheep are natives of a temperate climate; but bears and ermine of the coldest;—hence we find the clothing of animals in the torrid zone, hair—in the temperate zone, wool—in the frigid, thick fur. Linen conducts heat much better than wool; and hence its coldness, when applied to the skin, and its less absorbent powers of the moisture of the skin. Wool is, therefore, a more wholesome clothing. This power seems to depend on the texture of bodies; for spongy bodies, such as wool, feathers, &c. touch in so few parts, that they absorb heat from the bodies of animals, slower than bodies that touch with a greater number of parts. Besides, wool and fur inclose a great quantity of air, from their open, porous nature; and air, as well as water, is a bad conductor of heat. 5th. I take this glass bulb in my hand, Fig. 19, and hold it inclined as in the figure; the fluid, rarefied into steam by the heat of my hand, is forced up into the upper bulb; but as soon as it disappears from the lower bulb, and begins to boil in the upper, an intense degree of cold seizes my hand. Why?—The steam flying off from the inner sur-

face of the lower bulb, takes along with it a portion of the fire in the surrounding bodies (whether in an active or a latent state), and induces the sensation of cold. For the less heat that is necessary to bring a fluid into the state of vapour, the more intense is the cold it produces. Hence, to wash the hands in ether, would benumb them more than snow. Ether applied to an inflammatory headache, cools it and gives ease: applied to the root of the nerves behind the neck, stops a bleeding nose, &c. If the bulb of a thermometer be dipt in ether, spirits of wine, or any fluid that easily evaporates, and then exposed in the air, the quicksilver will sink a few degrees; for the fluid on the bulb flies off in vapour, and carries with it a portion of the latent fire of the quicksilver. 6th. Hence evaporation cools the earth, the sea, and even the human body; for the blood, in health, is no hotter in a warm than a cold climate—as may be proved by putting a thermometer under the arm, in various parts of a long voyage; for heat causes perspiration, and perspiration is evaporation, which carries off fire as fast as it is induced by the hottest sun: and hence the equal temperature of the blood in hot or cold climates.

SECTION VI.

On latent Heat.

1st. IF two bodies of the same kind, but of different temperatures, be brought into contact, they will soon acquire a common temperature, and the quantity of heat in each will be equal;

shewing that the hotter body has imparted half its surplus of heat to the other. The bodies, therefore, to which we apply the thermometer, should be large; so that the heat it gives out, or receives, may not sensibly affect their temperatures.

2d. The capacity of bodies for retaining fire, or heat, is greatest in the vaporous state, less in the fluid, and least of all in the solid state. For all bodies are susceptible of these three states. Example. Water below 32 of the thermometer, is solid; from 32 to 212, it is fluid (or in a state of fusion); at 212, it flies off in vapour. Water is kept in its fluid state by the pressure of the atmosphere; but that pressure is overcome by the repulsive force of fire, when its heat amounts to 212; and then, in the gasous state, the fire is carried off as fast as it can be administered to it: for boiling water, in open vessels, cannot be made hotter by the greatest increase of heat. Ex. 2. Crude iron, at 130° of Wedgewood's scale, becomes fluid; and the focus of a large lens will disperse it in the character of gas.—So it is with all other bodies.

3d. All bodies absorb heat, or fire, by a kind of chemical affinity; some in greater, and others in less abundance; and more in fluids than in solids: and yet they shall be of the same degree of sensible heat. If a sponge and a piece of wood be immersed in water, the sponge will soon be saturated with water; the wood not so soon, nor will it contain so much. We should say, then, the sponge has the greater capacity for imbibing water, though on its surface it is not more wet. So it is with different substances attracting fire; some imbibe more, some less, yet both are equally warm. If ice be put in water, the water will be brought down to the temperature of the ice, viz. 32; and will continue at that

temperature (though the water and ice are placed over a fire), till the ice be dissolved. What becomes of the superfluous fire? Doubtless it is absorbed by the ice, till it is all melted. So when the fluid is forced into vapour by an intense fire, that vapour is never hotter than 212, the boiling point; because the vapour absorbs the superabundant fire, and carries it into a latent state; a state that does not affect the thermometer. But suppose a piece of ice, cooled 20° below the freezing point, and a thermometer stuck in it, and both exposed to a hot fire; the thermometer will rise very uniformly till it comes to the freezing point 32, and there make a full stop, till the ice is all liquefied, and the fire will seem to have lost its faculty of heating. But after this, the thermometer will rise regularly, till the water becomes heated to the boiling point, viz. 212, and then it will become stationary again.—What is this but two stages of absorption?

4th. If equal quantities of frozen and fluid water (each at a temperature of 32), be exposed over a fire, the water will become heated to 162, before the ice is all melted, the ice preserving the temperature of 32 during the whole time; so that the 130° of extraordinary heat, produced no other effect on the ice, but to render it fluid. For bodies passing from a fluid to a solid state, universally emit a quantity of heat; as may be seen by applying a thermometer to water, in the act of freezing, which will be found several degrees warmer than the air about it. So, *vice versa*, when bodies pass out of the solid into the fluid state, they steal, from the neighbouring bodies, a portion of their natural fire, and leave them cold. Snow, or ice, and salt, liquefying together, have their capacity for the reception of fire so increased, that they draw it from all the surrounding bodies. Hence vessels containing cream,

water, &c. immersed in this mixture, will have the cream, water, &c. instantly converted into ice. Nitric acid poured on ice (even near the fire), will produce the same effect. And solutions of Glauber and ammoniacal salts, in thin glass vessels within one another, have frozen quicksilver, and made it an hard and ductile metal. But this, Nature has done at Petersburg and Hudson's Bay, in a cold 39 degrees below zero, or the cold produced by a mixture of salt and snow.

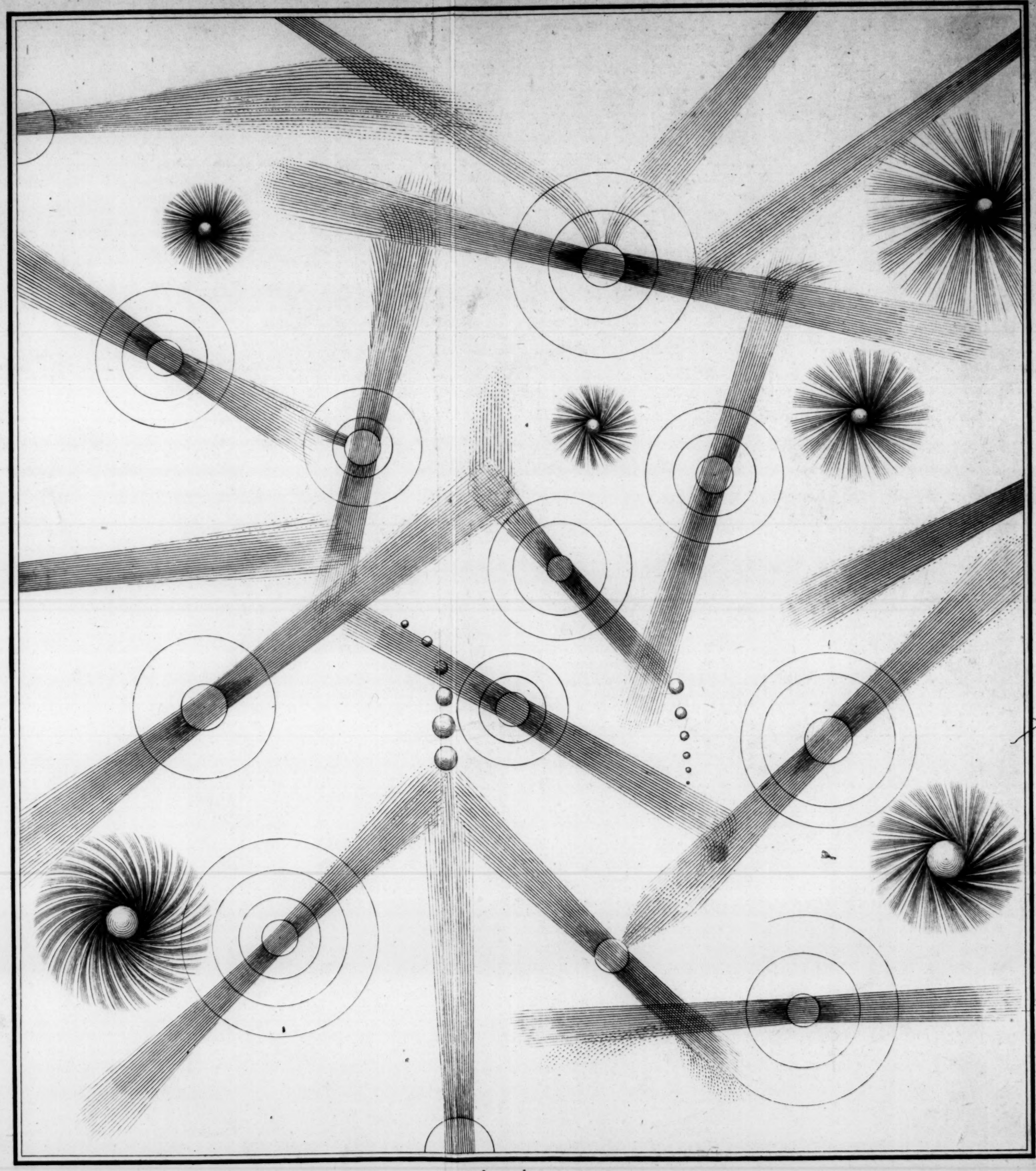
5th. Fire (being a constituent part of bodies, inherent in, and latent, till called forth by combustion, fermentation, change of capacity, &c. into an active state, and capable of affecting the thermometer) is not perceptible to our feeling in its combined or neutralized state. But if the capacity of the body which contains it be altered, it will soon become sensible. This piece of iron feels cold in my hand; I lay it on an anvil, and beat it with a hammer, and it becomes hot; and if the strokes be continued for some time, it will become red hot. Why?—Its capacity to retain fire is altered; the parts of the iron are forced into a closer union, and the latent fire is squeezed out, as water out of a sponge. 2d. I force air into the ball of an air-gun; the ball grows warm, yet there is neither friction nor compression induced on the ball:—no, it is the condensed air within, whose latent fire is squeezed out, and communicated in an active state to the containing ball. 3d. The Indian rubs two dry sticks together, and they ignite. The wheels and pinions of swift-moving machines take fire. A horse-shoe has its fire beat out by the pavement; and flint and steel lend their aid to destroy mankind. Fire is contained in a quiescent state in all these: rubbing or friction alters the texture, and con-

denses the parts of bodies, so as to force out their latent fire, and make it sensible. Even water, surrounding the borer of a great gun, has been made to boil.

SECTION VII.

On the Affinities of Fire.

1st. FIRE, so chemically united in bodies, may be decomposed, or separated from them, by various means; such as more powerful affinities, fermentation, effervescence, breathing, &c. for it has its chemical affinities, as well as the more gross bodies of the chemists. Its strong affection for metals will be shewn hereafter; but its extrication from the air we breathe, and the food we eat, more immediately assimilates with our present subject. We are instructed that the air probably consists of three ingredients in its unadulterated state, viz. oxygen gas, or vital air (constituting about one-third of its mass); azotic air, and fire. Air taken into the lungs, undergoes a decomposition; much of the vital part uniting itself with the blood: the azotic part is thrown out, with a quantity of fixt air (or carbonic gas); and the latent fire is let loose in the lungs, and carried by the blood, in an active state, through every part of the body, producing animal heat. The decomposition of our food in the stomach also extricates a quantity of latent fire, which, joining *that* deve-



Barlow sculp.

Fig. 4.

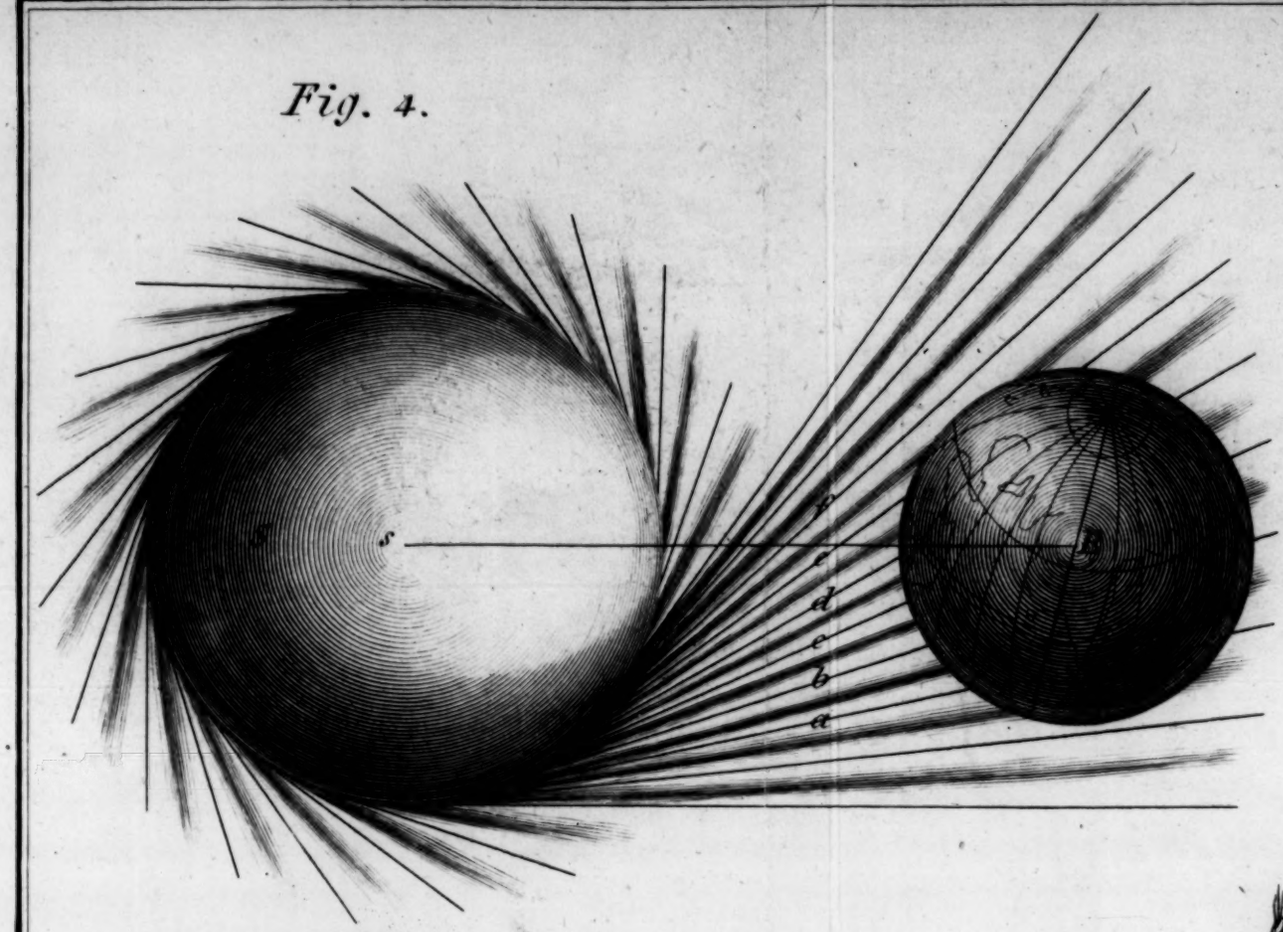


Fig. 5.



Fig. 1.

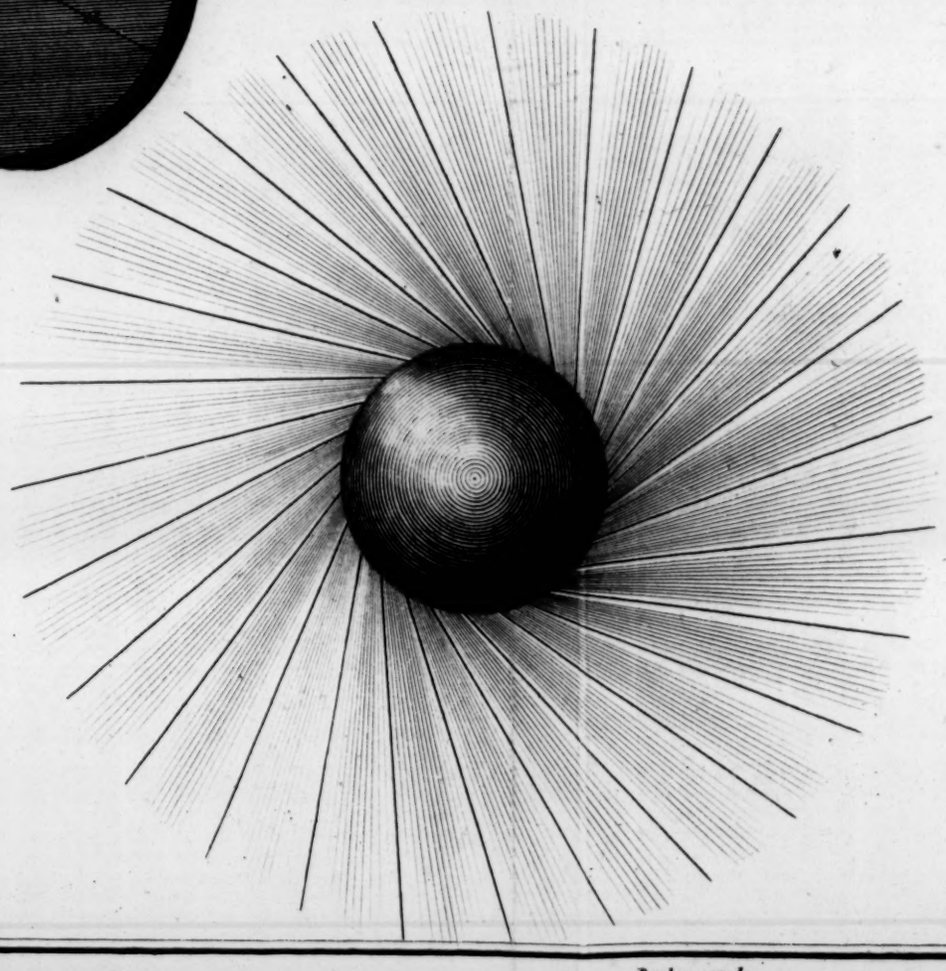


Fig. 7.

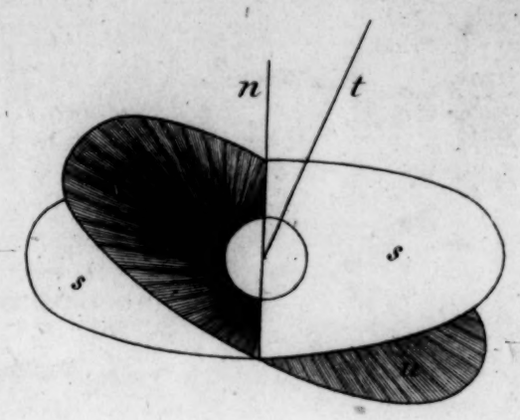


Fig. 6.

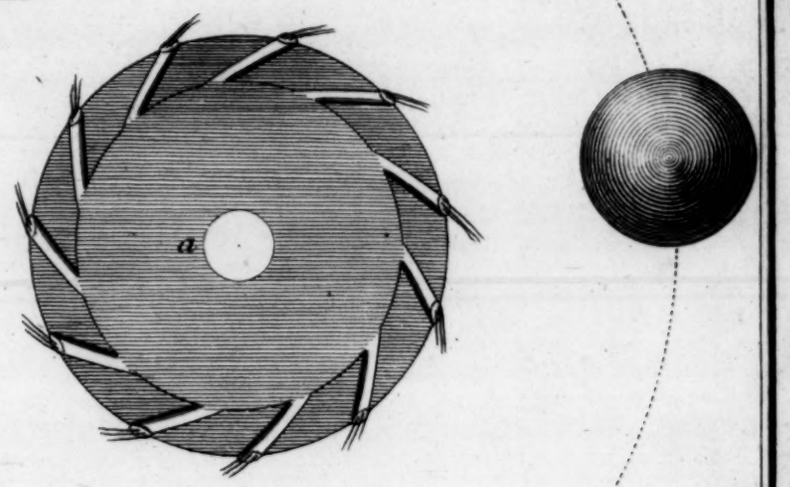


Fig. 3.

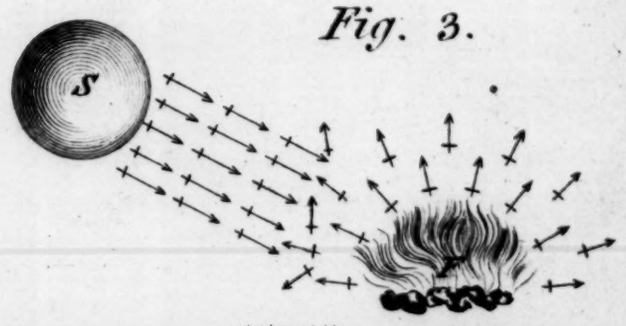
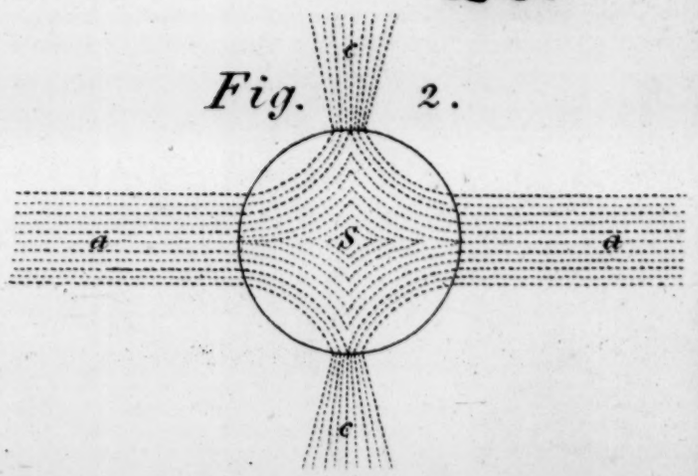
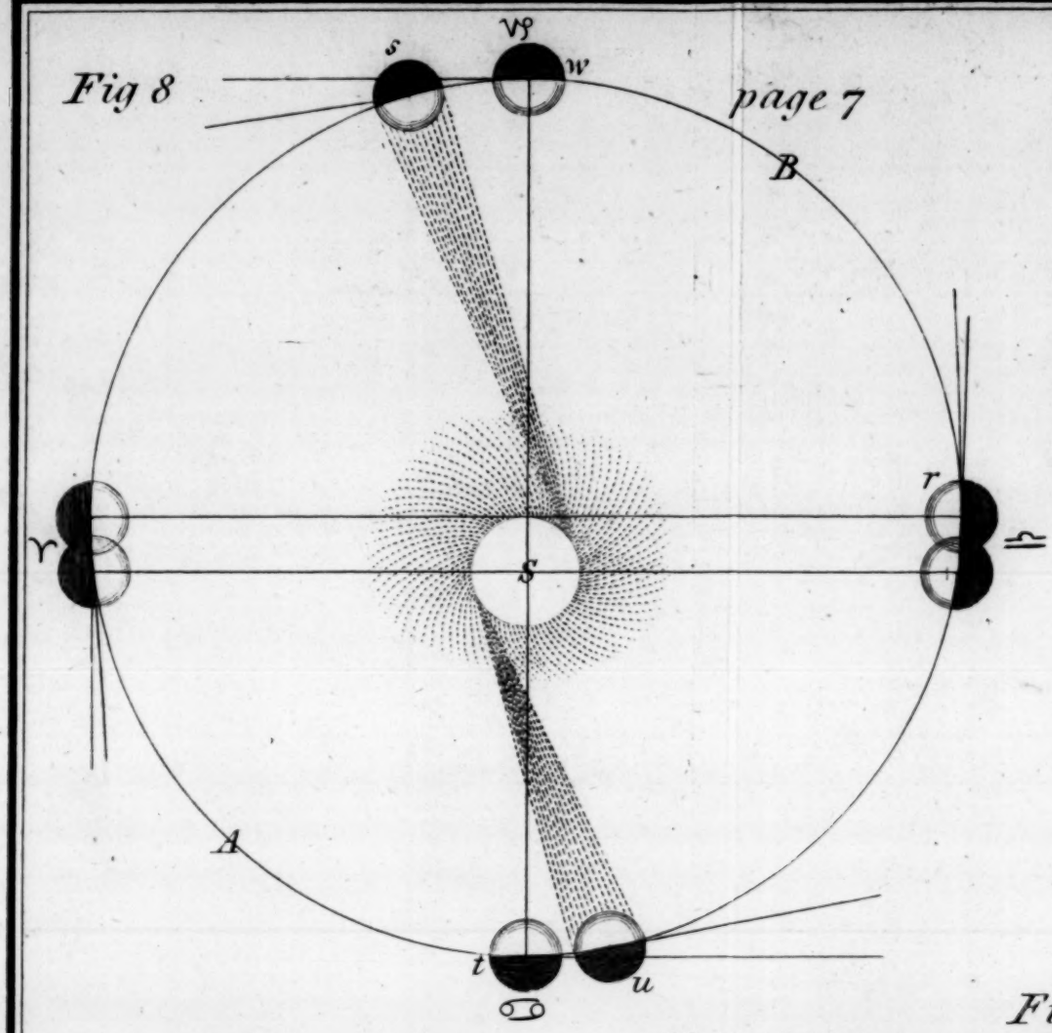


Fig. 2.



Barlow sculp.

Fig 8



page 7

Fig. 8.

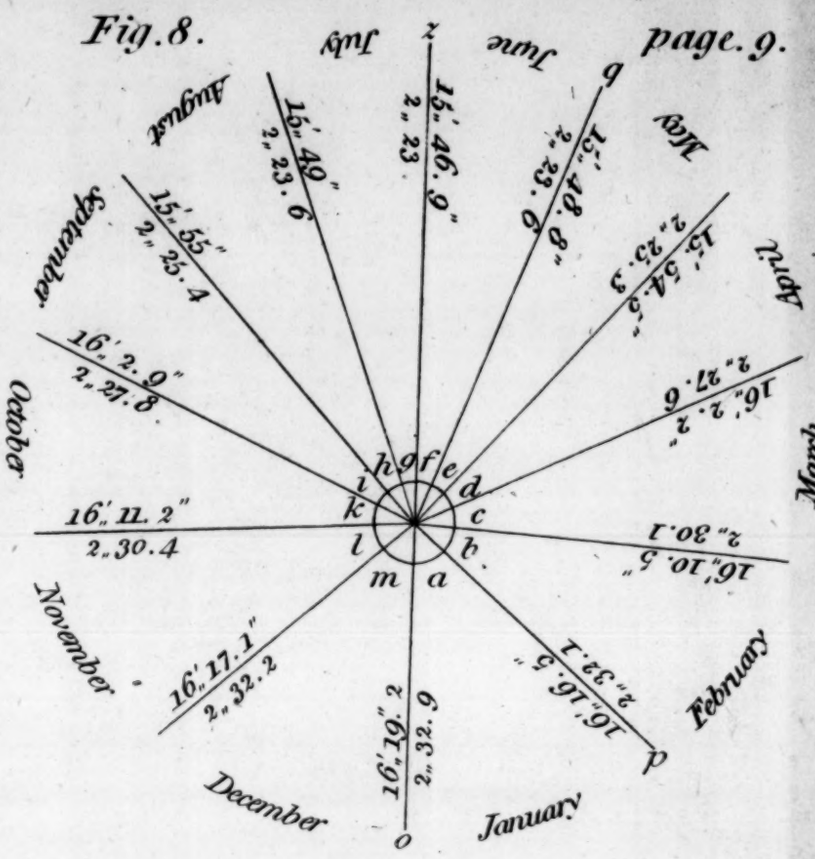


Fig. 9.

Fig. 15. p. 16.



Fig. 13.



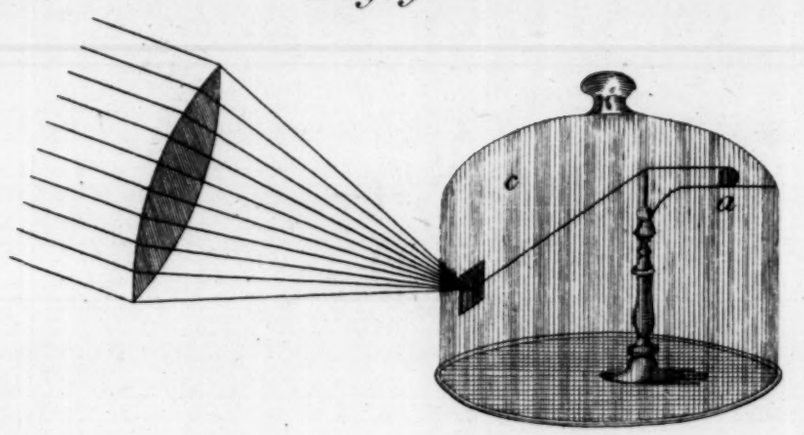
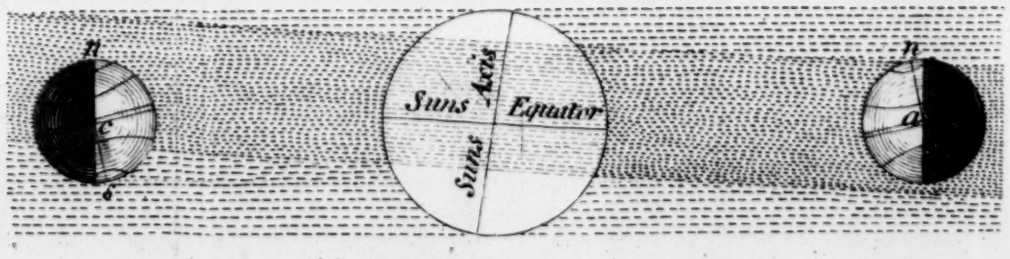


Fig. 2.



Barlow Sculp!

EFFECTS of HEAT.

Fig. 15.

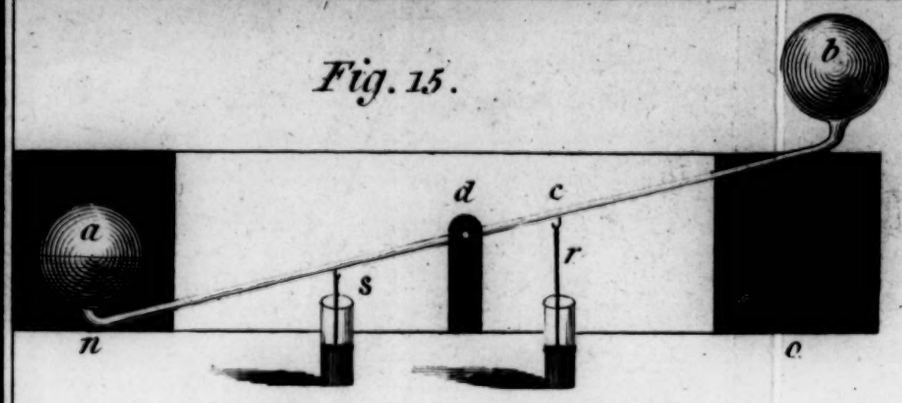


Fig. 16.

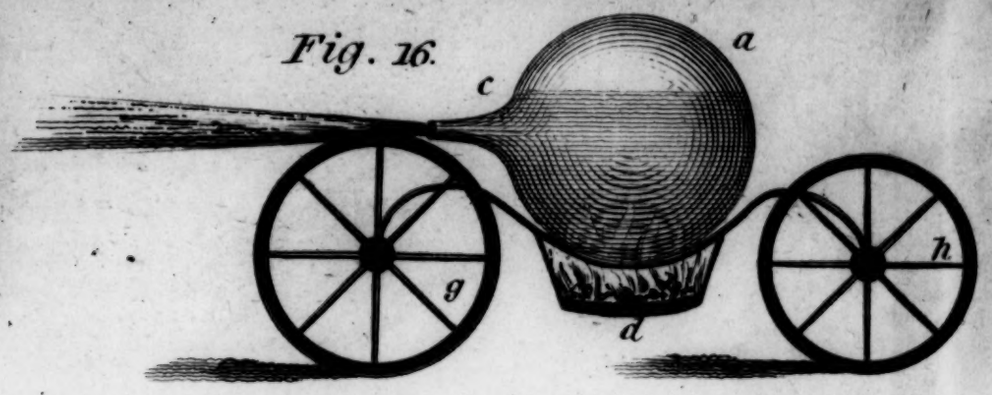


Fig. 20.

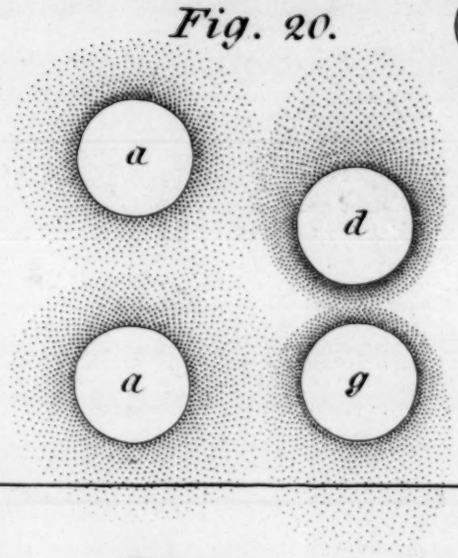


Fig. 19.



Fig. 18.

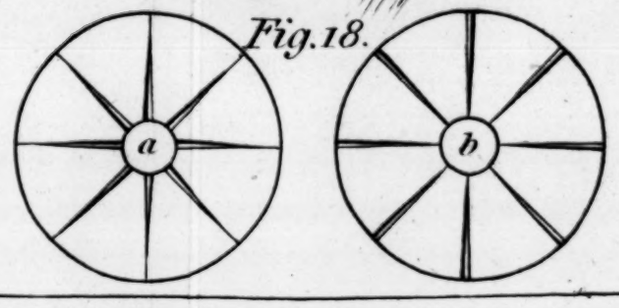
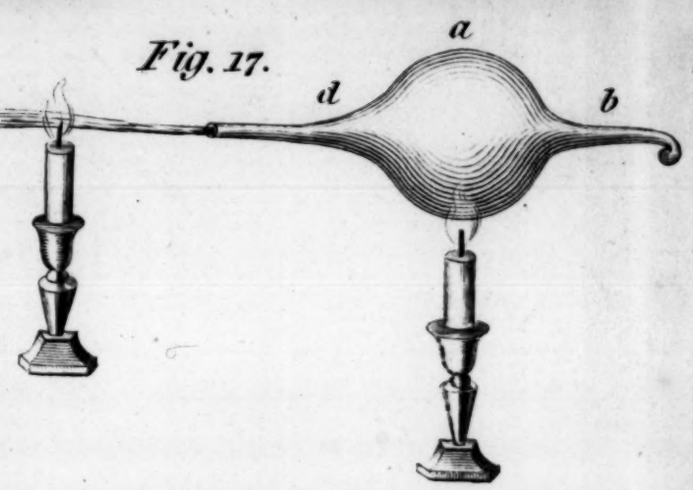


Fig. 17.



MECHANICS.

Pl. I.

Fig. 7.

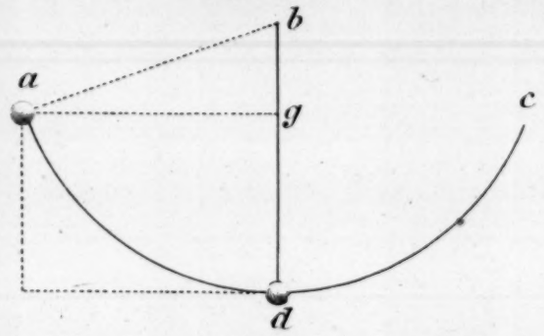


Fig. 2.

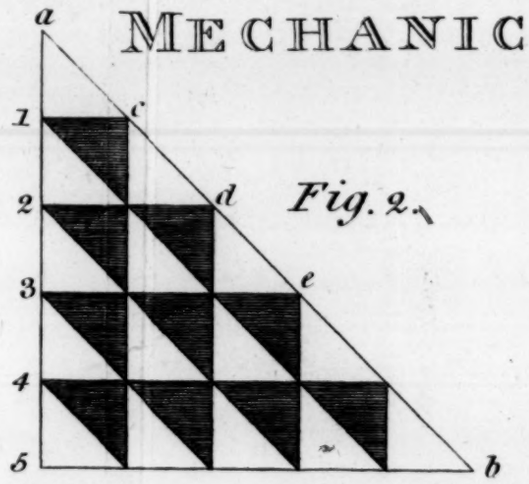


Fig. 1.

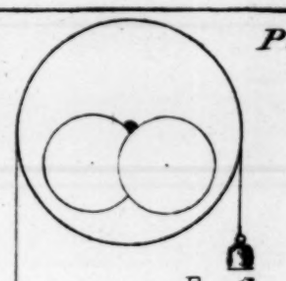


Fig. 3.

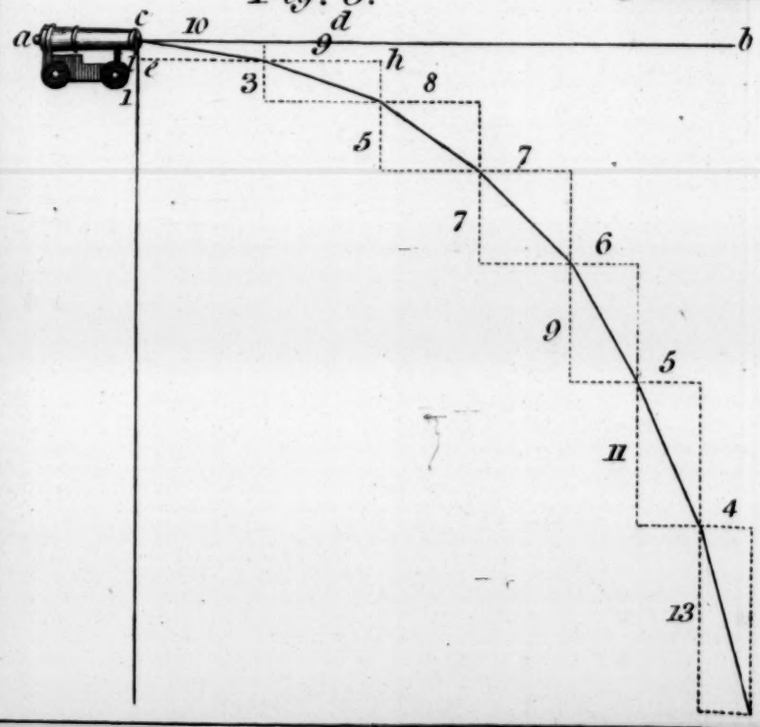
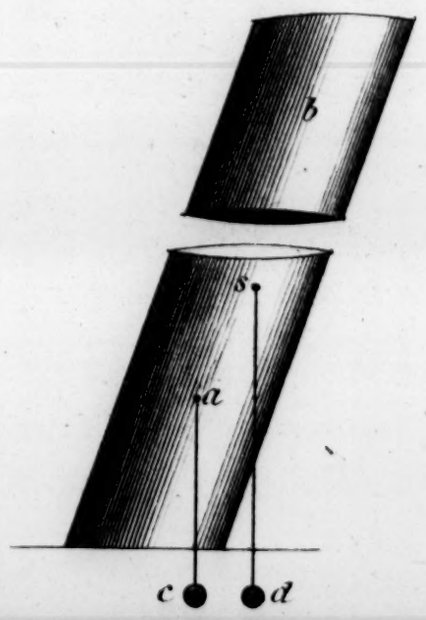
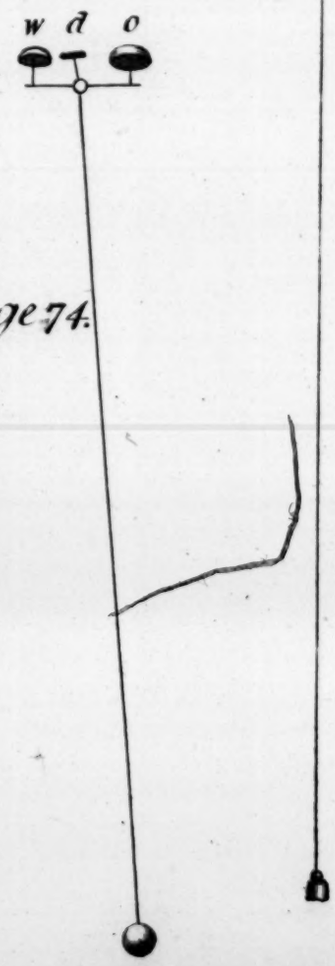
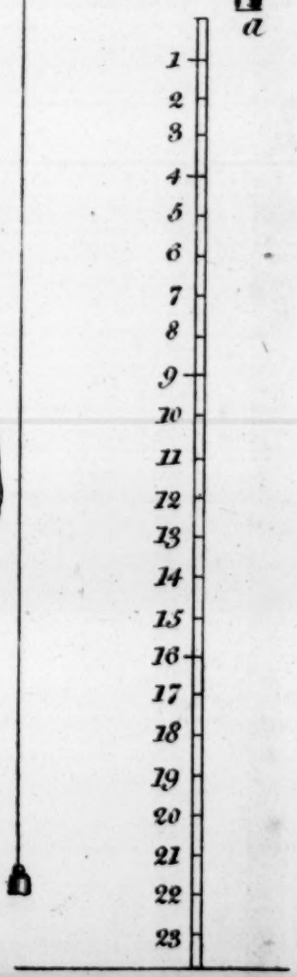


Fig. 14. page 74.







Barlow sculp.

loped in the lungs, gives that steady warmth to living animals, unknown to the inanimate parts of nature: and hence animals, without lungs, are of the same temperature as the mediums in which they live; as fish, frogs, &c.

2d. That bodies are not disposed to draw fire into a latent state, until they arrive at their melting point, nor fluids to part with it, until cooled to a certain degree, is evinced by the slowness with which ice and snow melt, when a thaw comes on, and the heat of the air is far above the freezing point; this abundant heat is absorbed by the melting ice, and prevents the country from being deluged by so rapid a thaw, as the warm air would seem to indicate. It is owing to this, that the ice is preserved in ice-houses, and snow on the mountains, even in summer heat. Water, at rest, may be cooled several degrees below the freezing point, before it will congeal; but if touched with the end of a wire, a bit of ice, or if the vessel be agitated, in an instant it becomes solid. If a thermometer be in the water, it will instantly rise up to the freezing point; and prove that a quantity of latent fire has emerged from the water.

These few examples will suggest more; and shew by what simple causes the greatest and most wonderful effects of nature are produced!—They lead us by degrees to the first cause, the Author of such uniformity, amid such infinite variety!

END OF THE FIRST LECTURE.

LECTURE II.

Of the Particles of Matter, their Minuteness, Hardness, Extension, Divisibility, Inertia, and Cohesion; and on Magnetism.

SECTION I.

PHILOSOPHY, like the sciences, has its first principles: matter and its properties are the objects of its research: by matter we mean every thing solid or fluid in nature, and we conceive this matter to be made up of particles so infinitely small, as not *only* to escape the scrutiny of the highest magnifying powers in glasses, but that even imagination itself is incapable of forming any idea of the size of an original particle of matter! When we have reduced matter to the most impalpable powder, we are far, very far, from the atoms which compose that powder. I dissolve a single grain of copper in an ounce of diluted nitrous acid; this solution will cover 1000 square inches of bright iron completely with a skin of copper, or impart a green colour to a gallon of water. One pound of gold is capable of covering a wire, that will circumscribe the globe! Musk, assa fœtida, camphor, and many other essences, will exhale for weeks, and throw off their particles to the distance of several yards, without losing any sensible weight! Nay, Lewenhoeck discovered more living animalculæ in the milt of one single cod-fish, than there are men, women, and children, on the face of

the earth! We deal not in those subtilties, where the whole matter of the universe is supposed capable of being compressed into the size of a walnut; or where an inch of common matter may be extended to the size of a world; they serve only to perplex enquiry, and by no means to promote the progress of truth: they will be studiously avoided in the following lectures. For while the mysteries of religion engrossed and perplexed the studies of our forefathers, the metaphysical spirit thence engendered, infused itself into philosophy; and hence the solemn definitions and unintelligible jargon, respecting extension, divisibility, impenetrability, &c. It is certainly self-evident, that every body must have extension in length, breadth, and thickness; that one particle cannot be thrust through another, nor one body occupy the place of another, while that other is in it. We have, indeed, many reasons to believe the original particles of all matter to be impenetrably hard; not only from experiment, but in order that nature might be immortal and incapable of wearing out. Electric matter (the subtilest matter we know), in passing through the human constitution, gives a real mechanic stroke to the ends of all the bones it meets in its way. In its explosions, it causes a vacuum in the air, the parts of which rushing together, after the explosion, produce the reverberated crack we call thunder. Must not the air and electricity be, therefore, made of hard particles? We tie a soaked bladder over one end of an open cylinder *a*, Fig. 20, and dry it slowly by the fire; if then it be placed upon the plate of an air-pump, and the air under the bladder be exhausted, the column of air *b*, will, by its weight, burst the bladder, and falling on the pump-plate, make a report equal to a pistol. Could this be the case, if the particles of air were not hard? Water also, like air, yields to the lightest impression; its particles slide over each other, with the utmost ease; yet water

falling through a vacuum, on metal, or any hard body, will strike it with as loud a click, as if one piece of iron fell on another. The water hammer, as it is called, proves this; the space *a*, Fig. 21, is a vacuum, *b* is water. Now if the glass be inverted, the water will fall into the bulb *a*; if it be then suddenly turned into its first position, it will fall on the bottom *c* with a loud click. This effect does not take place when the vessel has air in it; for air divides the water that falls through it, and prevents its striking the vessel in a body, as it does in the above vacuum. Must not the particles of water, therefore, be hard?

SECTION II.

BUT one of the most wonderful affections of matter, is its property of attracting and being attracted. Every particle of matter has a tendency to unite with other particles, if not prevented by the repulsive power of fire (or caloric), or a stronger affinity, as will be proved hereafter. The cavillers at the Newtonian doctrine, quarrel with the word attraction; and much waste paper has belumbered the world, in disputing whether it is a cause or an effect. It is natural to suppose that one body cannot act upon another, but by means of some interposing medium; but we have never been able to discover what this medium is. We know that the particles of matter are held together, by some sort of influence they have upon each other; and why not call it attraction? What is it to us, whether it is inherent in matter, or a quality imparted to it by the Author of nature? Its effects and operations, addressed

to our common senses, are the objects of philosophical enquiry. Before we proceed further, it will be necessary to note a few axioms, respecting attraction and repulsion.

All bodies, whether solid or fluid, are compounded of attracting and repelling matter.

Bodies, in which the attracting and repelling matter are equal, will balance, and neither attract nor repel, as *a*, &c. Fig. 20; where the repellent matter is represented by the dotted lines.

Bodies that contain more attracting than repelling matter, will attract with a force proportionate to the excess of attracting matter.

Those bodies whose repellent fire is not confined to their interior parts, but emanates round them in the form of atmospheres, while they are at a distance will neither attract nor repel, as *a*, &c. Fig. 20; yet when they are forced nearer together, so that their atmospheres begin to mix, unite, and coincide, they will then begin to attract. On their approach, the repellent particles that compose their atmospheres, will be forced backwards behind the bodies, as *d* and *g*; so that when the bodies come to a certain distance from each other, there will not be so many repellent particles between them sufficient to balance their force of attraction; on which account they will run together, and their atmospheres will so mix and unite, as to make up but one atmosphere to both.

When bodies are pressed together, the repulsion on their surfaces reacts as a spring. When bodies are stretched, as a musical string,

if distended as far as where the repulsion begins to take place, their force of attraction will be then overcome, and the string breaks. So in bending springs, one side is compressed, the other expanded; and therefore both effects take place. So that when attraction prevails in bodies, they become solid; when fire prevails, they become gas; fluidity, therefore, seems a medium between the two. Let us try then, in the first place, to prove that such attraction exists. Press two glass plates together, whose surfaces are even, and you'll find how difficult it will be to pull them perpendicularly asunder. I scrape the flat bottoms of two small leaden cones pretty even, then press them together with a small twist (to unite the particles better, not to link them), and find 100 pounds will scarcely separate them. In short, the particles that do really touch in the opposite surfaces, adhere as strongly as the particles that compose either cone; for had every particle in one surface, come in contact with the particles of the other surface, then would the two cones have become one mass, as much as if they had been cast in that form, when in a state of fusion. If the two flat stones with which we grind colours, be suffered to rest for a minute, they become almost immoveable; to continue their motion, requires little strength. This attraction therefore is gradual, when particles are deranged, or lie inconveniently by one another. Two iron planes, polished mathematically even, adhere so strongly, that twenty-four strong men have tried to pull them asunder, without effect. Two marble planes ground perfectly flat, have a little oil spread over them, to fill up such interstices as are usual in stones; when pressed together, a steel-yard is applied to determine what weight will pull them asunder. The planes are then pressed together as before, and suspended through a collar of leathers in the receiver of an air-pump, and the air exhausted. The steel-yard then applied to the wire which comes

through the collar of leathers, separates the planes in vacuo, with the same weights as in the open air (allowing a little for the friction of the wire and leathers). This shews that the attraction is totally independent of the weight or pressure of the atmosphere. Why do drops of rain, on the leaves of plants, assume a globular form? or why are they globes in their descent from the clouds?—Why does water become convex, when its surface is raised above the edge of the containing vessel; or concave, when the edge of the vessel is above the water? Or why do two globules of quicksilver run together, and form one globe?—Balance a piece of board on the end of a scale beam; then let it lie flat on water, and six times its weight will not separate it from the water. These, and ten thousand similar effects, might be brought to prove that it is an attraction among the parts that produces all these effects. Place pieces of cork on still water, about an inch distant, and they will run together with an accelerated motion; or, if near enough, creep to the side of the vessel. Nay, the largest ships sailing near one another in the same direction, have been known to run foul of each other, in spite of the rudder. The above experiment I know has been objected to, because if a piece of cork be placed near the edge of the vessel, when it is a little more than brim full, it will recede from the side; but this, I apprehend, does not invalidate the doctrine; for certainly the water which rises up the sides of swimming bodies, specifically assists their union; for very light and dry bodies, which lie on the surface of water without becoming wet, have not so powerful an attraction: hence the same attraction which makes the water rise globularly above the vessel, will draw a light cork from the side towards the centre; as the power or energy of this attraction is in proportion to the quantity of matter, the buoyancy of water, the solidity and distance of the attracting bodies.

By the same attractive power are formed stones, metals, woods, salts, and every thing that may be denominated body. The effects of solders, glue, cements, &c. are all from the same cause. So jewels, hardstones, stalactites, petrifications, porcelain, pottery, bricks, flags, glass, cements, artificial stones, and plastic earthy compositions, which preserve their figure in drying, all are children of that great agent, attraction.

The particles of air and water also mutually attract each other, as may be proved by exposing concentrated acids, or fixt vegetable alkali, to the air, which will soon attract and detach a sufficient quantity of water from the air, and become fluid. It is also evident in the drying of wet clothes in air; in the quick dissipation of moisture breathed on glass, polished metals, &c. in hygrometers; in water deposited by cooled atmospheric air; by air cooled after passing through red-hot tubes; and by water precipitated from air, while rarefying on the air-pump.

As this power is much greater in some bodies than in others, there arises an infinite variety in the strength, the weight, the texture, &c. of metals, stones, &c.; for we have powerful reasons to believe that the original particles of all matter are of the same weight; and that it is the attraction of cohesion that makes the great difference in their specific weight. To minds not used to philosophical investigation, it must appear a bold assertion to say, that the particles of gold are not one whit heavier than the particles of cork: but what says experiment and observation to this? Suspend two or three guineas, with a feather on each, on the shelves *a*, Fig. 3; the tall glass being then exhausted, the guineas and feathers may be dropt by means of the trigger *b*, operating

through a collar of leathers, and will strike the bottom at the same instant, if the glass *c* was even five or six feet high. Why then do not heavy and light bodies fall equally swift through the air or water? Because these fluids form a great resistance to bodies that pass swiftly through them; and this resistance being in proportion to the swiftness and surface of the bodies, if the feather is as large as the guinea, they will be equally resisted in their passage through the air; but then as the guinea contains so much matter more than the feather, there is a balance in its favour, by which it will overcome the resisting medium, and fall faster; but where that resistance is taken away (as in the exhausted receiver), their particles being equally heavy, they fall exactly in the same time. Otherwise, how should gold be suspended in a liquor, little heavier than water? for gold can be dissolved in aqua regia, like sugar in water; and its leaves float in air. If the particles of gold so separated, were heavier than the menstruum in which they are suspended, they would surely sink to the bottom.

Water is, bulk for bulk, 850 times as heavy as air; yet water will rise in air, because its particles, separately considered, are no heavier than the particles of air; the two elements mutually dissolving, and incorporating with, each other. Iron becomes homogeneous with diluted sulphuric or vitriolic acid; and its oxyd, or calx, will remain incorporated with it. Copper is dissolved also by diluted nitric acid. So is glass, or silicious earth, with sparry acid. Are not iron, copper, and glass, heavier in their natural state, than the menstruums in which they are dissolved? Certainly. But some will say these are chemical attractions; so they are: but let those who are fond of multiplying causes, demonstrate to me, that chemical attractions, are not modifications of the attraction of cohesion. Of this hereafter.

SECTION III.

On Capillary Attraction.

CAPILLARY attraction is only another mode in the action of the attraction of cohesion. It is called capillary from the tubes, which draw water above its level, being small as hairs. These tubes attract, in proportion to their bore or diameter; the smallest, having their opposite sides so contiguous, they give great assistance to each other, and draw the fluid two or three inches above its level. But wider tubes having their opposite sides too distant, draw it not above a few tenths of an inch. For the sphere of this attraction reaches but to a very small distance from the surface of bodies.

Two wet glass planes, Fig. 4, separated on one side by a shilling, and immersed in water, when lifted out, will exhibit a curve, called the hyperbola; that ſhews the ratio of this attraction to be as the squares of the increments with which the planes open, viz. as 1, 2, 3, 4, &c.; as 1, 4, 9, 16, &c. And here it may be observed, that the laws of nature seem generally to be regulated by the squares of numbers; as if that had been a principle in the Almighty Mind, when he created and gave laws to the universe.

It is inconceivable the multitude and variety of operations in nature, that capillary attraction explains. All vegetables are but bundles of capillary tubes; and whether we consider earth, water, salt, and oil, as the food of plants—or, with Kirwan, that coal is

essential to that food—or with Ingenhouz, that it is vital air decomposed into fixt air and azote; still that food must be formed by water into an emulsion, capable of being acted upon by capillary attraction; and as all roots are but assemblages of these tubes, there can be little doubt but their attraction supplies the plant with its first food; though other causes must assist in carrying it to the tops of the tallest trees, such as contraction and dilatation, by the successive heat and cold of day and night; the muscular action of vascular rings round the tubes irritated to contraction by the stimulant sap, &c. The interior bark conducts the nourishment supplied by the earth. Leaves draw nutrition also from the air, by their capillary pores; and light probably does the rest.

This principle is not less active in the animal than the vegetable world. The stomach may be called the animal root; and by its action, and the gastric solvent in it, food is also formed into an emulsion, and acted upon by absorbent or capillary tubes, under the names of lymphatics, lacteals, &c. drawing the finer part in a milky state to the heart, where, uniting with the venal blood, it is taken up with it to the lungs; and, from the air in them, derives its red colour. All the secretions in the intestines, &c. are carried on by the same law. Even the skin itself may be said to be little more than capillary pores, through which emulsions may be rubbed, forming the topical applications of surgery. In civilized life, these pores serve, in general, to throw off redundancy, and help digestion. We eat and drink more than nature requires; the ordinary evacuations are not enough to carry all off; much perspires through the skin: and it is well known, we in general lose more weight by what is called insensible perspiration, than by any other evacuation whatsoever. Hence arises the necessity of a perpetual change of

our linen and clothes; for what are they but bundles of capillary tubes, absorbing this matter from the skin. Dip your handkerchief in water, and the water creeps up it, above its ordinary level. Touch its surface with a sponge, the water rises in it above its level. Raise a heap of sand in a flat vessel full of water, the water will rise to the top of the sand above the water. Glue is attracted into the pores of wood, and becoming hard, forms the bond of union between two pieces of wood. All these instances, and thousands more, are the effects of capillary attraction.

Nay, a living body is capable of deriving nutrition, even through the pores of the skin. The lone savage lays him down naked on his parent earth, when fatigued with long marches and hunger, and finds that hunger abated by the contact his body has with the ground. Nor should we be incredulous when we hear of a late Empiric, who could live for weeks together, by burying himself to the neck in earth: when every sailor knows, that in a scarcity of fresh water, he dips his jacket in the sea, and putting it to his naked skin, finds his thirst allayed by that expedient. The resources of nature to preserve animal life, are wonderful in the extreme!

SECTION IV.

On the Polarity of Matter.

THE diversity occasioned by the unequal attraction in metals, stones, &c. is much increased by what may be called the *polarity of matter*; or that mode of arrangement, which different substances take in passing out of a fluid into a solid state. For all bodies are capable of three states, viz. solidity, fluidity, and a *gassous* state. Water, at 32 degrees of Fahrenheit's thermometer, is cold enough to become solid, in the character of ice; a little heat, and the pressure of the atmosphere, makes and keeps it fluid, and we then call it water; but if that heat be increased to 212° of the same thermometer, it will overcome the pressure of the atmosphere, and fly off as gas, in the character of steam. So iron will preserve its solid form, till it be heated to 130 (Wedgewood's scale). It will then become fluid, and the heat increased will disperse it as gas. Even diamonds, the hardest substances we know, are capable of being dispersed by a common culinary fire; though gold, in its pure state, bids defiance to the utmost power of heat. It has been kept boiling in the focus of the largest lens ever made, for eleven hours, without losing a grain of its weight. Though when its particles are separated by its solution in aqua regia, it easily assumes the gassous state, with a small degree of heat. This, therefore, is not considered as any exception to the axiom, that all bodies are capable, in certain circumstances, of the three states of solidity, fluidity, and gas. But the polarity of bodies arises from the man-

ner in which the particles approach, and lay by the side of one another, when the fire that kept them separate, subsides, and the attraction of cohesion draws them together into a solid: for if fluid iron be disturbed in cooling, it will not have all the properties of iron; it will become solid; but it will want the natural texture of iron, its colour, and some of its strength. If water be stirred with a stick, while freezing, it will not be ice, though it will become solid; for water is a salt in a state of fluidity, and crystallizes in a certain degree of cold; and its polarity, or mode of arrangement, even in its solid form, may be seen on the frozen moisture of a window. The forms assumed by different salts, arise from the same cause. Even metallic arrangement may be considered as crystallization. Hence metals differ from metals; stones from stones; wood from wood; &c. and add to the immense variety occasioned by the different degrees and force of cohesive attraction. Light angular bodies, swimming near one another on water, will run together, and unite their sides, in the most convenient manner, to make one body; illustrative of the manner in which the particles of matter arrange themselves in the act of crystallization, as in Fig. 5.

SECTION V.

On Magnetic Attraction.

MAGNETIC attraction is confined to iron, steel, and the natural magnet, which natural magnet is a ponderous iron-stone, of a blackish colour. This wonderful stone is supposed to derive its power of attracting and repelling, from the position in which it laid in the earth: for, from the quantity of ferruginous, or irony matter, contained in the earth, as well as many other phænomena, there are strong reasons to believe the globe itself to be one great magnet. Steel, struck by lightning, or a strong ſhock of electricity, acquires polarity or magnetism: hence it is natural to imagine, there is a relationship between electricity and magnetism. If a bar of steel be balanced on a point, one part of the stone will attract it, and an opposite part of the stone will repel it. May we not apprehend this to be occasioned by a subtil effluvium, flowing from one end of the magnet, and entering at the other? These two ends are called the north and south poles of the magnet. The reasons we have to believe that this effluvium does exist, are:

1st. If iron filings be shaken through a gauze sieve, upon a paper that covers a bar magnet, the filings will become magnets, and be arranged by the incumbent magnet, in the beautiful curves seen in Fig. 6. Upon the two ends of the magnet at *a a*, the filings stand perpendicular, and seem buttresses of arches that

would stand over the magnet. On the sides of the magnet they slope, or incline, and seem buttresses of inclining arches; so that if filings could be sustained all round the magnet, they would probably assume an egg-like figure. Is not this appearance favourable to the idea of an effluvium, flowing all round the magnet from one end to the other, and having a circulation through it?

2d. If two pieces of spring-tempered steel, formed like horse-shoes, as *A* and *B*, Fig. 7, with the ends *a*, *b*, and *c*, *d*, be put together, and two bar magnets (separated as *e* and *g*, and their marked ends in contrary direction), be rubbed round the horse-shoe bars, with the bar *e* always foremost, magnetic virtue will be excited in the two bars, and they will adhere together. But making this cohesion as it were an hinge (by laying the bars upon each other), if then the four attracting ends be placed together on a piece of iron, they will not attract it, but seem as if they had lost their attractive power. Now if a circulating fluid be the cause of magnetism, it is natural to suppose this fluid must flow through the pores of the horse-shoe bars in the same direction in which they received it, viz. from *b* to *a*, and from *c* to *d*; and consequently that *b* must be a delivering pole, and *a*, a receiving pole. In like manner that *c* must be a delivering pole, and *d* a receiving pole: and this will be found true, if the pole *a* be held about an inch from one end of a suspended compass needle, it will repel it; but if *b* be addressed to the same end of the needle, it will attract it. In like manner *c* will repel, and *d* will attract. Now when one of the horse-shoes is laid on the other, with the poles *a b* together, and the poles *c d* together, it is evident an attracting and a repelling pole are put together, which must counteract the effect of each other, and make them seem as if they had lost their virtue, when placed on a

piece of iron; for one may be said to be pulling, while the other is thrusting. But if the receiving poles, *a* and *d*, be put together, and the delivering poles, *b* and *c*, be joined, when the bars are laid one on the other; then if the four poles are placed upon a piece of iron, they will immediately take it up. It is in this manner, and on this principle, the strong horse-shoe magnets are formed, where six or eight such bars are rivetted together. But in order to make a regular road for this subtil effluvium, it is necessary a piece of iron should always be in contact with the attracting and repelling poles, by way of a magnetic conductor.

3d. Two semicircular magnets, *A* and *B*, Fig. 8, having their poles dipt in iron filings, the filings will stick radiantly to the poles in every direction. If the pole *a* be brought within half an inch of the pole *b*, and the pole *c* at the same distance from *d*, the filings will leave their radiant direction, and catch hold of the filings of the opposite poles: for *a* and *c* being delivering poles, and *b* and *d* receiving poles, a magnetic circuit is formed, and the filings become conductors. But if the pole *a* be addressed to *c*, and the pole *b* to *d*, the filings will not unite, but repel those opposite to them, as Fig. 9. In one case, the magnetic effluvium has a regular circular road; in the other, the fluid of one magnet meeting the fluid of the other, a repellency takes place. Are not these experiments strongly indicative of a magnetical effluvium?

4th. The efforts which this wonderful principle will make, to *accomplish* itself a road, by means of iron or steel conductors, are beautifully exhibited, by suspending three or four small iron balls, by one of the poles of the magnet, Fig. 10. If then a piece of iron be made to touch the other pole, and suddenly to communicate with

that by which the balls hang, the balls instantly fall from the magnet. These balls may be suspended by either of the poles (for they will make equal efforts to form a conductor); but so soon as the bar *q* has completed the circuit, the balls are forsaken, and drop off.

5th. When three of the balls are suspended from each pole of the above magnet (for except the magnet be very strong, it will not sustain more perpendicularly), if two others are so added, that they all touch each other, they will adhere circularly to the two poles, and form the image, Fig. 11. Can this be for any other reason, than because the balls and the magnet make one complete magnetical circuit?

6th. If several steel bars be placed in a line, touching each other, and the north (or *marked* end), of an horse-shoe magnet be slid foremost over them several times, in the same direction, the bars will adhere to one other, and be all lifted by one of the bars. If then they are placed as at first, and the *unmarked* end of the magnet be slid foremost over them, as before, the attraction of the bars will be destroyed, and they will not betray the least signs of magnetism. Must not this arise from confusing the magnetic circuit? and turning that into a receiving, which before was a delivering pole?

7th. If one end of a poker (or any bar of iron, that has for any length of time stood in a perpendicular position), be held near one end of a compass needle, it will attract it; but if the poker be moved slowly, in its first position, till its other end comes near the needle, the needle will be repelled. Is not the poker a magnet?

Beyond a doubt. But how came it so? By standing in the way of the earth's magnetic effluvium. For if a new-forged needle be balanced on a point, and then have magnetism given to it, by either a natural or artificial magnet, and be suspended again on the point, it will be found to have lost its balance, and will point so as to form an angle with the horizon, of about seventy-three degrees; see Fig. 12. This is called the dip of the needle; and is most rationally accounted for, by its effluvium falling into, and becoming influenced by, the stream of the earth's magnetic effluvium. Iron railing, upright bars in windows, tongs, pokers, &c. all become magnetic by their upright position.

8th. If a small thin piece of steel be suspended by its centre of gravity, between two fine points, and placed on one end of a bar magnet, it will stand perpendicular to the bar: if it be then slid towards the other end of the bar, it will begin to incline towards a level: at the middle of the bar it will hang horizontally, and then incline and stand with its other end, perpendicular to the bar.

Is not this a proof, that the globe of the earth is one great magnet? and that a similar effluvium flows through it, as through those magnets thus described?

9th. Take the poker *a*, Fig. 13, hold its knob near one end of the compass needle, and it will attract it: keep the knob in the same situation, but turn the poker upon it (as on a centre), into a contrary position, as *b*, and instantly the knob will repel that end of the needle it attracted before, and attract the other end of the needle; shewing, that the poles of the poker were changed by the change of position. This experiment succeeds best,

when the poker points towards the earth's magnetic pole, at an angle of 73° with the horizon; for then it is parallel with the earth's effluvium, and partakes, as it were, of it; so that, when the point of the poker is upwards, it receives the effluvium, and becomes what is called a south pole; and its other end is a north pole, and attracts the south pole of the needle. But when it is inverted, and the knob points upwards, that end of the poker becomes the receiving, or south pole, and consequently repels the south pole of the needle; conformably to the idea, that a subtil *something* flows through the earth, the sea, and the air, that has a peculiar affinity to iron, steel, and the natural magnet; making these substances into magnets, by only being in its way.

As iron, or ferruginous matter, is more particularly diffused through the body of the earth, than any other metal, and that in a reguline form (for iron ore is not attracted by the magnet), this effluvium can never be in want of its conducting matter: but why that power should assume those serpentine and other forms, we see in the lines representing the needle's variation, is yet unknown. Some suppose that the diurnal rotation of the globe, or subterranean fires, may cause this singular arrangement in heavy materials, and also occasion their removal westward. But this is merely conjecture; no observations yet made, give it the least countenance.

10th. That this virtue has a *direct* tendency, is evident; for if a steel wire (rendered magnetic), be twisted into a spiral spring, the virtue is strangely confused. It will attract in some places, in others repel. Nay, in some places, one side of the wire will attract, and the other side repel; shewing the disposition of the fluid to flow forward.

11th. A bar of iron made red-hot, and quenched in water, or cooled in air, standing in the position of the dipping needle, will acquire magnetism. Does not the earth's magnetic fluid, flowing through the ductile metal, adapt or arrange its pores, both for the reception and retention of magnetism?

12th. For the same reason, if a bar of iron be fixed in the direction of the dipping needle, and rubbed all one way, with the end of a steel bar, or even a pair of tongs, the iron will become a magnet.

13th. A smart stroke of a hammer on the end of a bar, standing in the direction of the dipping needle, will give it magnetism; and the poles may be changed by striking the other end.

14th. If a bar, in the above position, receive a smart electrical shock, it becomes instantly a magnet; the end towards the earth (or rather towards the north magnetic pole) becoming a north, or delivering pole, and the other a south, or receiving pole; and it is well known, that a stroke of lightning has often changed the poles of a mariner's compass needle.

15th. That iron receives a magnetic virtue, by standing in the direction of the earth's magnetic effluvium, is not more remarkable than its acquisition of magnetism, by being held lengthwise near the poles of an horse-shoe magnet; when, by trying it with iron filings, it will be found to hold them at each end, as if it had been regularly impregnated. Nay, if so heavy a piece of iron be

held to the poles of a magnet, that it cannot sustain it, if another piece be held a little below it, the magnet will sustain it.

16th. These arrangements and polarities, are beautifully exemplified, by filling a glass tube with iron filings; if the tube be touched by a magnet (as if it were an iron bar), the glass will appear to have acquired magnetism, and will attract filings. But shake or disturb the filings within the tube, and all magnetism disappears.

How far these observations and experiments go, to establish the doctrine of a magnetic effluvium flowing through the earth, or from one end of a magnet to the other, must be left to the reader's judgment and opinion. We are apt to laugh at the *subtil matter* of Des Cartes, and the *ether* of Euler, as occult qualities, which modern philosophy will not admit into its creed. But this effluvium is a subtil matter, an ether, equally as inexplicable, and as equally out of the reach of our five senses to scrutinize; but if we may venture to guess at causes by effects, and to compare analogies with what we can see, feel, &c. I think we have infinite data in favour of magnetic effluvia, superior to any proof that can be brought, of ether being the cause of gravity, light, vision, &c.

SECTION VI.

Miscellaneous Observations.

SMALL magnets have a stronger attractive power, in proportion to their size, than large ones; and sometimes a piece broken off a stone magnet, will be stronger than the stone itself: shewing the stone not to be homogeneous, but that some parts of it are more susceptible of magnetism than others.

Magnetic power may almost be said to be created by friction, rather than communicated by it; for a magnet acquires strength by giving magnetism to iron; so that if all the magnets in the world were lost, magnetism might be revived, by rubbing the end of one steel bar against the side of another.

It is highly probable, that the near approximation of steel, or iron, to the texture of the stone magnet, is the reason why some iron is more susceptible of receiving and retaining this virtue, than others.

Unimpregnated iron attracts the magnet, as forcibly as the magnet attracts it; (for iron seems to solicit the union by as forcible efforts, as the magnet itself). Hence, if a magnet be made to swim in a little boat, and a piece of iron be held stationary, at a little distance from it, the boat will move to the iron.

One magnet attracts another, with less force than it attracts iron: but the two magnets will influence each other at a much greater distance.

The north pole of a magnet, properly suspended, always points towards the north magnetic pole of the earth; and *vice versa*; and an heavy steel bar loses of its weight, when magnetized.

Files, and other hard steel tools, acquire temporary magnetism, by their friction or collision with iron.

Magnets lose their power by length of time, if left without those conductors, or pieces of iron, which form the magnetic circuit. For horse-shoe magnets require but one, as *q*, Fig. 10; but bars require two, as Fig. 10, No. 2; the bar *a* lying with its marked, or north, end *e*, in a contrary direction to the bar *b*, whose north end is at *f*. The conductors are *c* and *d*; so the bar *a* delivers its effluvium at *e*, to the conductor *c*; and the bar *b* delivers it at *f* to *d*; forming the magnetic circuit. In these positions, magnets retain their virtue for ages; and if, by accident, their virtue becomes impaired, it may be easily regained, by hanging a bag to its conductor, and increasing its weight with shot or sand.

Artificial magnets, made of hard tempered steel, are much stronger than natural magnets, and communicate the magnetic virtue more powerfully.

Flat bars, about one eighth of an inch thick, receive and retain magnetism better than when thicker; because, in hammering thick pieces, the interior parts cannot be arranged in the same

manner as the outside, but must form a resistance to the passing fluid.

Fire and rust injure the virtue, by confusing the direction of the magnetic stream.

If a natural magnet be broken into any number of pieces, each piece will have an attracting and a repelling pole; and the middle part between the poles, will neither attract nor repel.

If a steel sewing needle be rubbed, from its eye to its point, a few times over the north (or marked) pole of a magnet, and then stuck in a small cork, to swim in water; the eye will point to the north, and the point to the south.

Magnets exert their greatest power at their ends; for the wise purpose of catching conductors, to form the magnetic circuit.

If a piece of common iron be held to *one* end of a magnet (so that the grain of the iron and the magnet be in the same direction), the other end will lift more than it would otherwise.

The attraction and repulsion of magnets, is not diminished by the interposition of any other body. Small sewing needles may be made to dance on a table, by moving a magnet under it. Many magic pictures are made, and curious questions answered, by devices formed on this principle.

Whatever deranges or disturbs the pores of a magnet, injures its

magnetic force; such as strokes from a hammer, or other violent percussion, &c.

When small bars of soft iron are applied to the two poles of a natural magnet, and fixed there by thin plates of brass (called armour), as Fig. 10, No. 3, where *a* is the natural magnet, *b* and *c* the bars, the effluvium flowing all round the magnet, from one end to the other, is diverted through the conductor *e*, which will support a much greater weight, than the natural magnet unarmed.

Many substances seem slightly attracted by the magnet, besides iron; but it is known that almost every animal, vegetable, and mineral substance, contains iron; and hence they appear to be affected by the magnet.

A piece of iron held near a magnet, becomes a magnet itself for the time; and that end nearest the magnet acquires a contrary polarity; that is, one delivers, and the other receives, the effluvium, for iron must receive magnetic virtue, before it will be attracted.

If two magnets approach each other, with poles of the same name, they are mutually repelled at a small distance; but if brought into contact, they attract and stick together: for a stronger magnet will change the poles of a weaker, the instant they touch each other; like stronger light absorbing, or turning back, weaker.

SECTION VII.

On the Variation of the Magnetic Needle.

TO enumerate all the theories that, at different periods, have taken place about this mysterious phænomenon, would fill a volume. I reject the internal loadstone of Halley, because neither experimental or analogical proof can be had of its existencce; and its four poles account no better for the variation, than the two poles of Euler. Simplicity is dictated by nature, and I adopt its suggestions. Observation must be our guide.

Before any rational theory can be formed, we must premise a few postulata, that seem to lead to it: heat weakens the attractive power of all magnets. A compass needle has a periodical revolution by the heat of the day, and cold of the night; it will increase in variation from eight in the morning, till about one, then become stationary for some time, and before morning return to its first position. In the winter, this variation is about 6 or 7 minutes of a degree; in the summer, about 13 or 14′. This proves that heat is concerned in the general variation of the compass. 2d. The whole space included in the arctic and antarctic circles, may be said to be nearly *round planes*, with their edges presented to the sun; his rays falling, therefore, so oblique, and in so small a quantity, on these frigid zones, must occasion their excess of cold: but cold assists magnetic attraction; and as the baser metals are found more towards the polar than the torrid regions, iron is pro-

bably in greater abundance there, and may determine the place of entrance, or exit, of the earth's magnetic stream, and of course determine the place of its poles. For iron (even in a metallic state) is found, in most parts of the globe, in greater abundance than all other metals: and bar-iron acquires magnetism by standing parallel with the dipping needle in all parts of the globe, as iron filings do, by lying in the effluvium of a common magnet. This proves the earth itself to be a magnet. A strong shock of electricity passing through a piece of iron, will give it temporary polarity; but passing through hardened steel, the steel will acquire fixed polarity and magnetism. A stroke of lightning has, in like manner, given polarity to iron and steel; has made many sewing needles to stick together; and has changed the poles of the compass-needle. The aurora borealis also affects the needle with tremor and vibration: reinforced by many other reasons, these prove lightning, electricity, and the aurora, to be all the same, or electricity. If electricity, light, and fire, be but modifications of one and the same principle (as I hope will be proved hereafter), and they have their origin, or fountain, in the sun, it is natural to suppose, in issuing from that luminary, they proceed from him first in their purest state, or in the character of electricity; that joining the particles of our atmosphere, electricity becomes light, and uniting with the grosser earth, fire. The lower region of the atmosphere is an electric, or non-conductor, when very free from moisture; but the air, rarefied on an air-pump, till it becomes of the same rarity, or thinness, as the upper region of the atmosphere, is a conductor of electricity. Hence the difficulty electricity has in making its way through the lower air, after that air has been some time dried by hot weather, exhibiting thunder and lightning; and hence the ease with which electricity glides through the upper

air towards the poles, in the character of an aurora. This idea may be better understood by Fig. 16, where *A* represents the sun's rays falling on the upper air at *c c c*, and penetrating it as a conductor. At *d d* they penetrate directly, and forcing their way into the lower air, occasion thunder and lightning by its resistance, when that air is not moist enough to conduct the lightning to the earth. Hence the super-quantity of thunder and lightning in the torrid zone, than in the other parts of the earth. Motion being rectilineal, all matter in motion strives to go forward in straight lines, and the easiest way: the conducting part of the polar atmosphere is in a line with the sun's rays, as *c m*, and *c g*; and the parts *i i*, approach so near to the same direction, that it will be easier for these rays to slide down the conducting parts *c i*, towards the poles, than push into the non-conducting parts *a a*. Hence a condensation of electricity must take place, near or about the poles, and occasion the aurora borealis, and aurora australis, as at *r* and *s*; for when electricity is condensed to a certain degree, it always becomes visible. In this figure, the northern hemisphere of our globe is presented to the sun, as it is at our midsummer; and must, from its position, receive, within the arctic circle, more electricity from the sun, than can be received within the antarctic circle. May not the ferruginous matter of the earth conduct this superabundant positive quantity to the other pole, now in a negative state, and produce the horizontal aurora, seen streaming upwards towards a point, and generally in the north-west?—And is not this the reason why the streamers are seen only in the winter, or about the equinoxes? Electricity excites to more vigorous exertion the living principle of both plants and animals; excites quicker motion in fluids; excites the heart to a swifter pulsation; and may it not excite the latent, though inherent, principle of

magnetism in iron? For friction calls forth magnetism, as well as electricity: the act of making a bar magnet by rubbing, gives it electricity enough to affect a sensible electrometer. Electricity may be drawn from every kind of substance on the earth's surface; and the earth has, therefore, been called the grand reservoir of it: no doubt but it is diffused through the general body of the earth, and possesses those bodies most, to which it has the most affinity, or which are its best conductors. Now iron being more abundant in the earth than all other metals, and proved to have affinity with, and to be a conductor of, electricity; and electricity having the property always to endeavour at an equilibrium, wherever it is positive or negative; if the north polar regions be positive in summer, and the south negative, and *vice versâ*, then will there be a circulation through the globe between these polar regions, that may arrange the ferruginous parts of it into a magnetic axis, like the lines of variation, serpentine as *x x*, Fig. 16. As the northern hemisphere is exposed to the sun eight days longer every year than the southern, and as the extremes of heat and cold are much greater in the latter (see Astronomy), may not this be the reason why the south magnetic pole is farther from the south pole of the equator, than the north magnetic pole is from the north pole? For it is conceived that the north magnetic pole is somewhere about the arctic circle, and supposed by some to have a regular rotation round it, in a certain period of years; some think from east to west, and some from west to east; some think it regular, and calculate on that regularity; but more are convinced it is not regular: some argue that capes and islands retard its motion, and, therefore, that the north and south magnetic poles are not antipodes to one another; for the south magnetic pole seems, by the effect it had upon the needle of captain Cook's compass (which turned several degrees in

one day's sailing), to be about 144½° east long. and 59° south lat. By other accounts, it seems to be in 130° east long. and 66° south lat.; and others place it 165° east long. and 60° south lat.; so that it seems to shift backwards and forwards with too much irregularity, to form any theory of its cause, situation, or motion.

That a line, on every part of which the needle points due north and south, does run serpentine between those two magnetic points, is more than probable; for such a line is found near Cape Florida, running through the Bahama and Leeward Islands, passing over part of Guiana and Brazil, where it again enters the Atlantic Ocean, and is believed to pass over the real south pole to the south magnetic pole *c*, as denoted by the spotted line *a a*, Fig. 17. On the east side of this line, the variation is west; on the west side, the variation is east. Another line of no variation, is also supposed to originate at the north magnetic pole *d*, and to pass over the real north pole; after which it is really found to run through Siberia, Tartary, China, and the East-India Isles, along *b*; and from thence supposed to the south magnetic pole *c*. On the east side of this line, the variation is east; and on the west side, west; agreeably to the figures, shape, and disposition, of the serpentine lines on the hemispheres, Fig. 17.

Notwithstanding the irregular motions of these poles, and the lines of variation issuing from them, there are conformities that would seem to lead to a rule or theory. The line of no variation in 1700, passed from about Charlestown, South Carolina, north of the Bahama and Leeward Islands, serpentine towards the coast of Africa; by which it passed about one-third of the distance between that coast, and that of South America, towards the south pole.

Since that time, it has moved irregularly towards the west 30°, but so as to keep nearly parallel to itself; carrying the east and west lines of variation along with it. This seems as if the magnetic poles had a motion from east to west; though some affirm their motion to be from west to east: an hypothesis which has but one observation to support it, that can be much depended upon, viz. that the line of no variation passed over London in 1657, and not over Paris till 1666. But the imperfection of needles, and of observation at that time, might occasion this opinion; for as the lines of variation do certainly move westward, there can be little doubt but the magnetic poles move the same way.

It has been supposed, that the aurora, or northern lights, have the centre to which they generally tend, over, or in the zenith of, the north magnetic pole; and, therefore, when that is beneath our horizon (in its rotation round the real pole), those lights must disappear to us; and from thence may be inferred a reason for the vulgar opinion, that the streamers were never seen till the year 1714. In the writers of the dark ages we frequently read of armies seen fighting in the air, as portents of some impending wars, or other calamities: there can be little doubt but these were northern lights. However, there seem intervals in the appearance and non-appearance of this striking phænomenon; it has not been seen in England for several years; and if it could be proved that it followed the north magnetic pole, or was influenced by it, this would be a grand step towards ascertaining its period.

That these lights are electricity, many other proofs might be adduced. Light from fixed stars is not refracted, or bent, in its passage through the aurora; neither is the light from a candle, or

any other luminous body, refracted or bent in passing through the flames of electricity. Both the aurora and electrical light, viewed through the prism, exhibit the same colours as a ray from the sun, &c.

SECTION VIII.

On the Dipping Needle.

LET a bar of hard steel, Fig. 12 (unimpregnated with magnetism), be suspended horizontally between two nice points, so as to hang in equilibrio: if then it be touched, as before directed, and again suspended, it will be found to have lost its horizontal balance; in this part of the world it will incline, so as to form an angle with the horizon, of near 73 degrees; further north, it would incline more; and probably over the north magnetic pole, it would stand perpendicularly. Such needles, taken into various parts of the world, dip as in Fig. 14. On the magnetic equator *a b*, the bar would hang horizontally. At *c*, it would dip as Fig. 12. At the north magnetic pole *d*, it would stand like the lines, perpendicularly: *i. e.* at *a* or *b*, it would be so equally acted upon by both the north and south pole, as to obey neither; but as it approached *c*, its south pole would point through the earth towards the north magnetic pole, and incline in an angle, equal to the complement of the angle 73°, mentioned above.

If a loadstone be ground into a globe, the same dip and inclinations will take place upon it, as upon the real earth; see Fig. 15; where *a* is the terella or globular magnet, and *b*, a small glass globe, blown at the end of a capillary tube *c*. If a quarter of an inch, broken off the small end of a small sewing needle, be put into the bulb *b*, and the bulb be slid over various parts of the terella; in two places, the bit of needle will be found to stand perpendicularly on its ends; these places on the terella are its poles. The needle moved slowly from one pole to the other, will first incline a little, then more, till it is half way between them, or at the magnetic equator, there it will lie horizontally on the globe: on being moved forward, its lower end will begin to be elevated, and will become more and more so, till it arrives at the other pole, when it will stand perpendicularly on the contrary end. This is precisely similar to what happens to the dipping needle, when carried to various parts of the earth; and, therefore, the globular magnet is properly called a *terella*, or little earth. Filings strewed on the terella, will exhibit the same appearance; and if its magnetism has not been disturbed or deranged, by lying with, or near other magnets, the filings will appear on it, like Fig. 14. Otherwise, the filings often appear in little tufts, indicative of a disturbed magnetism; a circumstance, no doubt, to which the earth itself is liable, from the magnetism of it being found different at the same place, after a short space of time. This, I think, indisputably proves the earth to be magnetical.

SECTION IX.

Magnetic Amusements.

1. HOLD the north pole of a magnet *near* the south end of a suspended needle, and the needle will become agitated; and, with a vibratory motion, seem wishful to approach the magnet, for about half a minute, when the magnetic stream will become alike in both, and then the needle will be at rest.

2. A tee totum in motion, will be taken up by a magnet, as if at rest; and one or two more will hang to the first, though they turn in contrary directions. Young people are much entertained, by seeing a tee totum spin on its head, as well as on its foot.

3. The figure of a small swan, with an iron bill, may be made to shew its fondness for bread, and aversion to cheese, by sticking a piece of bread (with a wafer), on the north pole of a magnet, and a piece of cheese on the south pole; the swimming swan will follow the bread round a basin; but, on turning the cheese, he swims from it.

4. The figure of a small fish, having a piece of iron in its mouth, will follow a hook of steel magnetized, round a basin of water; and may be lifted out of the water by it.

5. The iron coffin of Mahomet is said to be suspended in the air, by a powerful magnet. A small coffin, made of very thin sheet iron, and fastened to a table by a black horse-hair, will seem

to hang under a magnet, as if without support; so that a quill, or ivory knife, may pass between the coffin and the magnet.

6. If in a pond of water, of about an inch in depth, and eight inches diameter, the above swan be placed, and on the edge twelve hours be marked, as on a clock face; and then a watch, having on its hour centre a light magnet fixed, be placed close under the thin brass bottom of the pond; when the swan is put in the water, it will swim to the hour and minute of the day, and tell the company what o'clock it is.

7. The divining circles are drawn on paper, pasted on the top of a thin box, *A B*, Fig. 18. The index *a* is fixed on the axle of the toothed wheel *c*, which works into the pinion *d*. On the axle of *d* is another pinion of the same number of teeth, that puts in motion the wheel *g*, of the same size and number of teeth as the wheel *e*. On the axle of *g* is fixed the bar magnet *q q*, and they turn together. Over this axle (but independent of it) is fixed a point for the loose needle *x x* to turn upon, and which is the centre of the pasted circle *F*, Fig. 2. In the compartments of this circle are written answers to the questions asked, in the compartments of the circle *G*, Fig. 2. A carton of strong paper, of the size of *F*, should cover the pasted circle, and turn easily on the centre *z*: it should have one of the triangular pieces, as *F*, cut out, in order to see the answers. If then the needle be taken off its point, and a person wishes to ask some of the questions on the carton *G*, the person must turn the index to the question, and then place the needle on its point, giving it a whirl round, when it will stop over the answer. The open part of the loose carton being turned to that place, will exhibit the answer.

Fig. 20.
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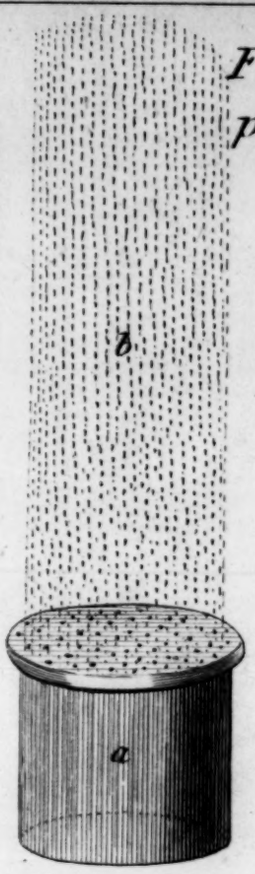


Fig. 21.

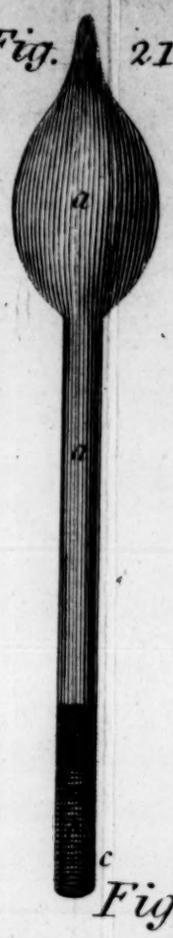


Fig. 4.

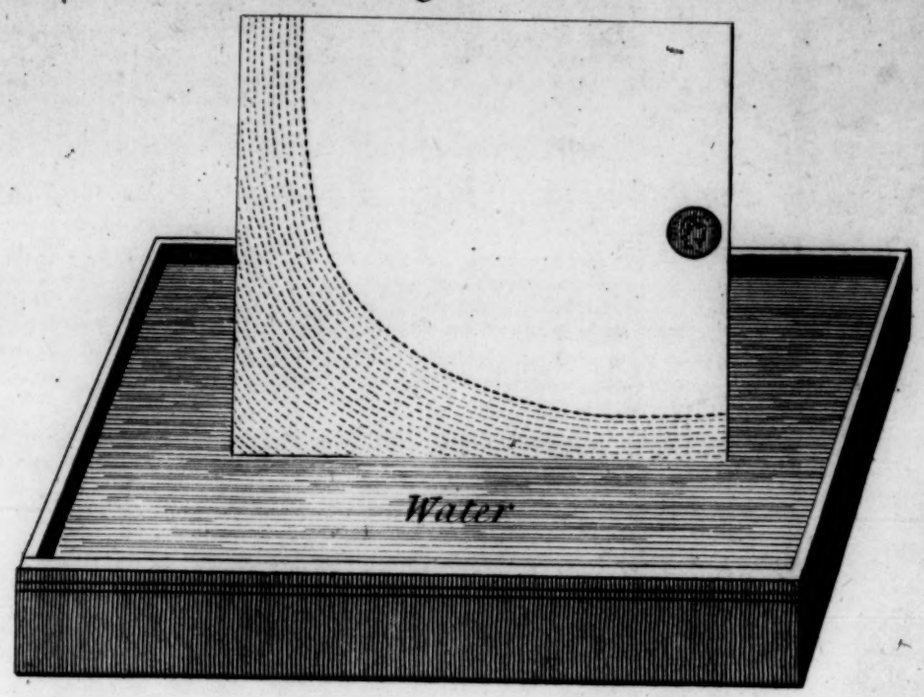


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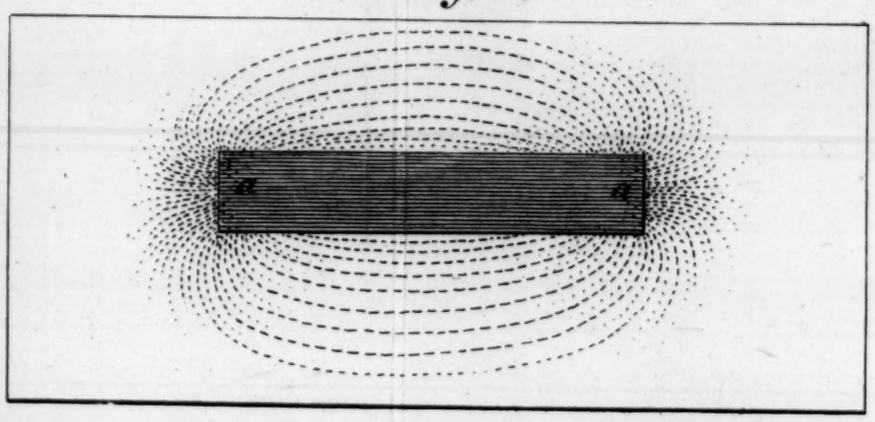


Fig. 5.

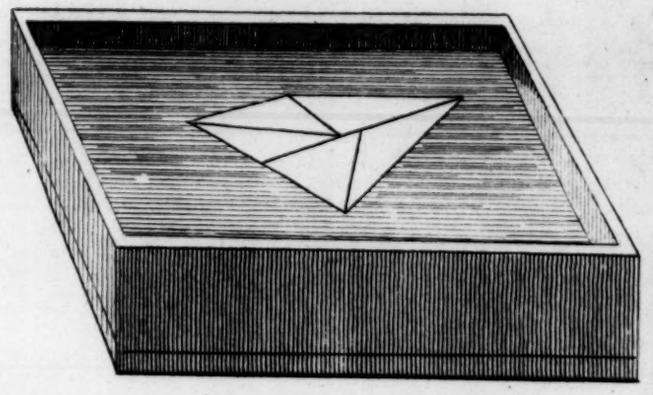


Fig. 3.

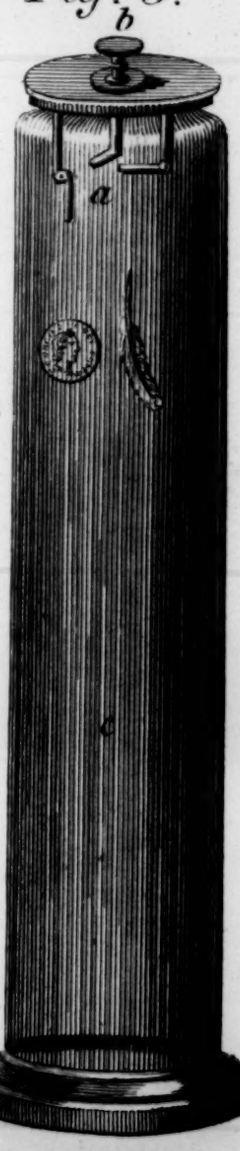


Fig. 7.

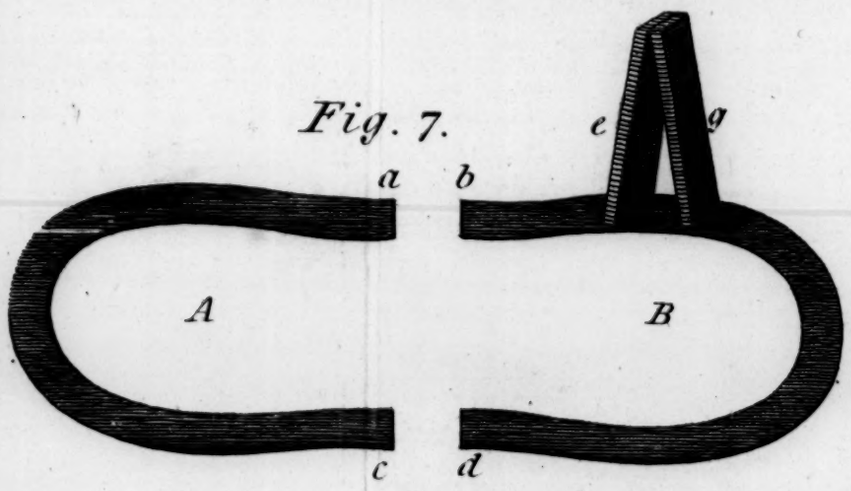


Fig. 10. N.o 3.

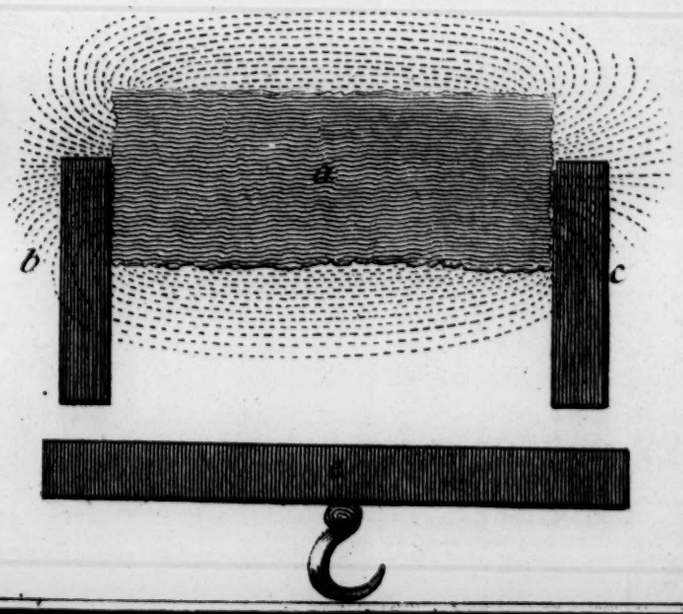
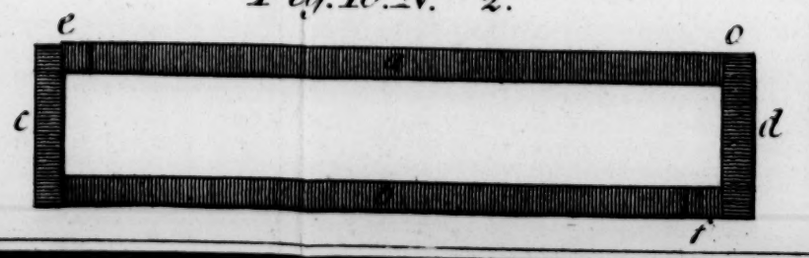


Fig. 10. N.o 2.



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Fig. 8.

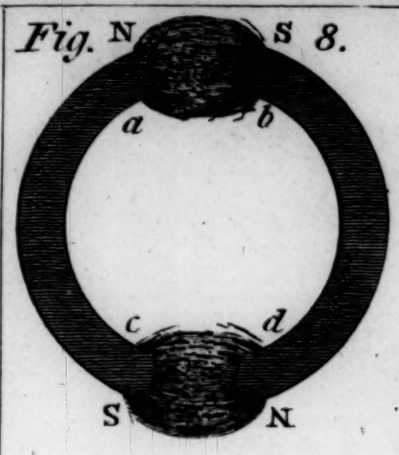


Fig. 9.

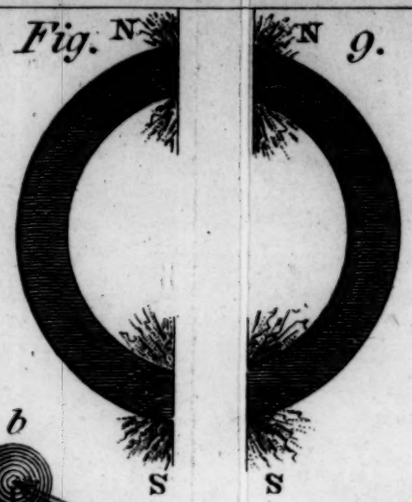


Fig. 10.

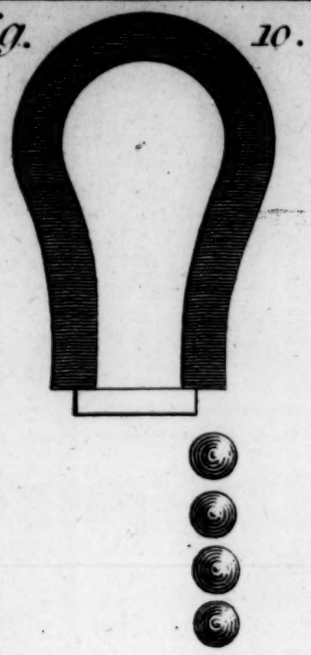
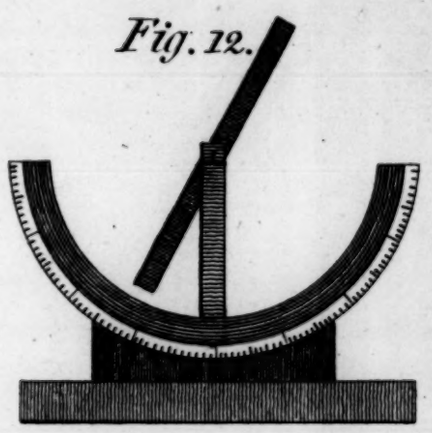


Fig. 11.



Fig. 12.





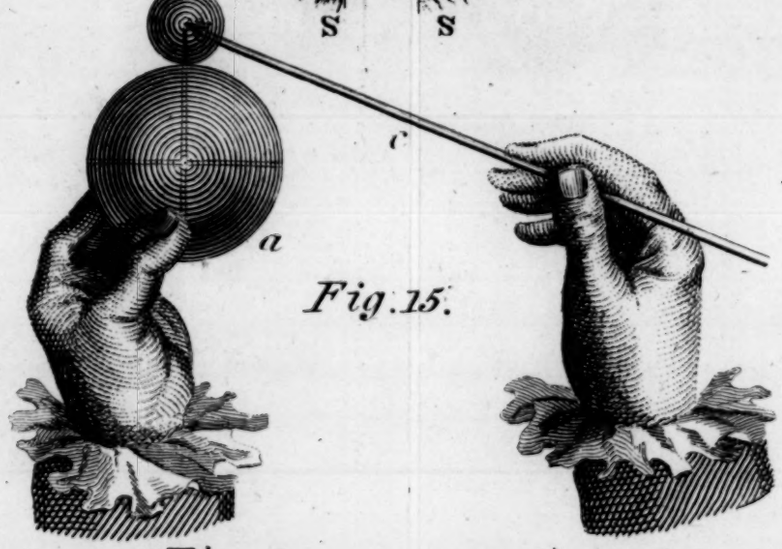


Fig. 15.

Fig. 6.

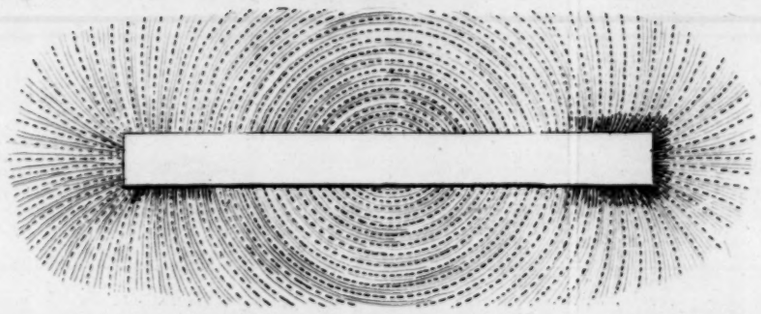
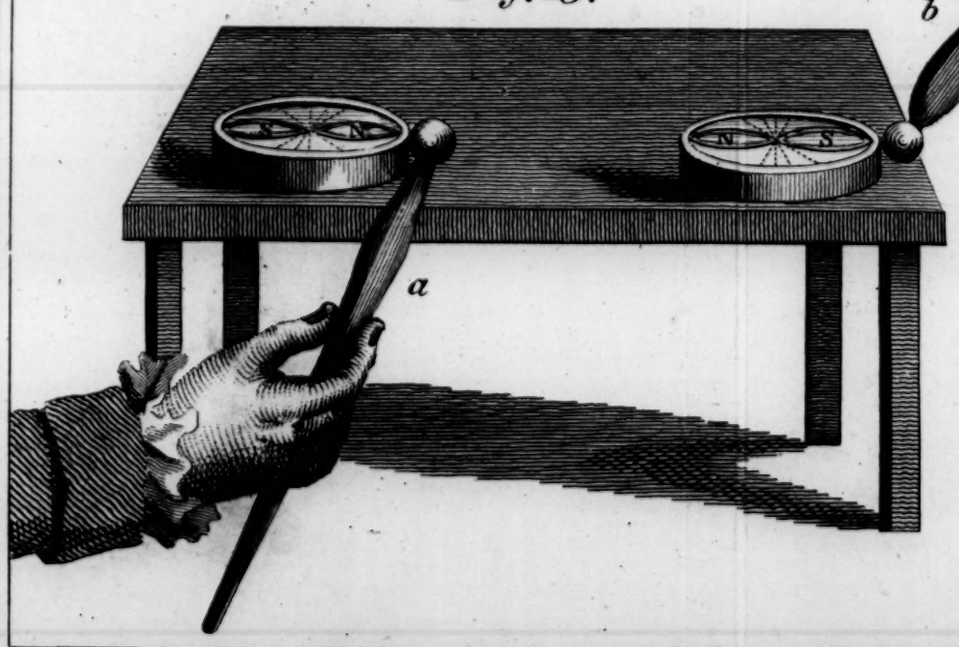
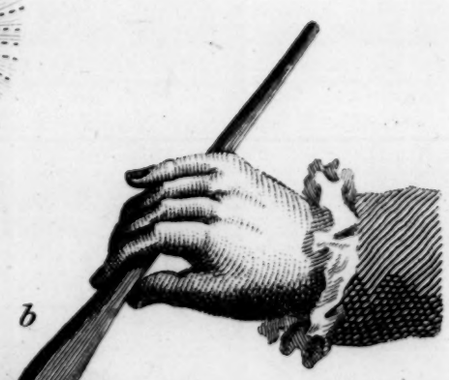


Fig. 13.





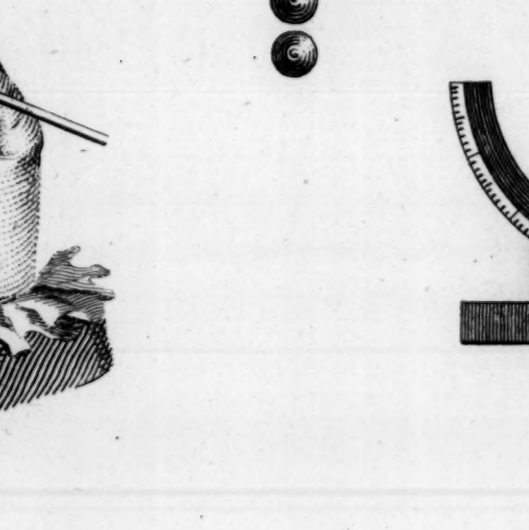


Fig. 14.



Fig. 14. page 16. d

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Fig. 17.

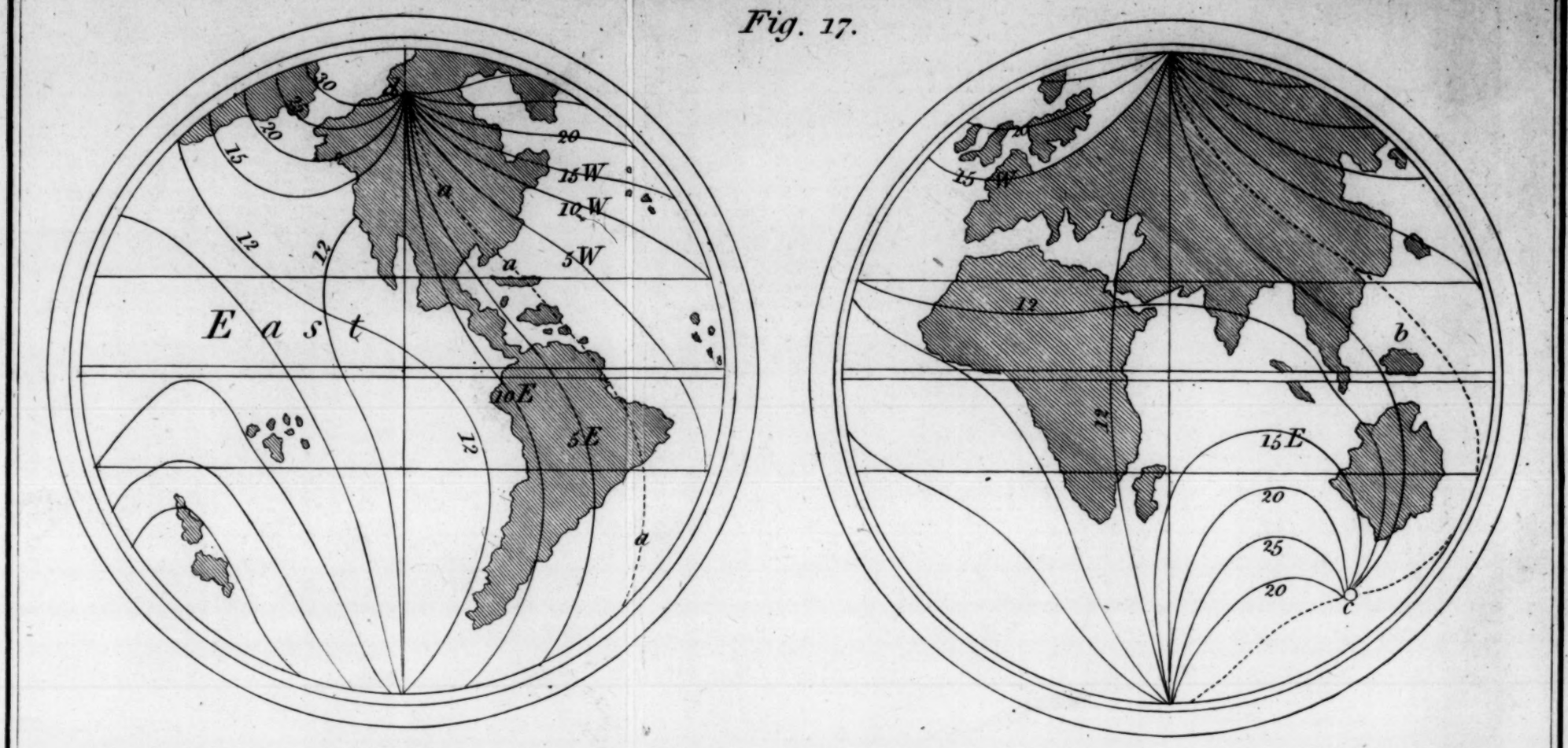


Fig. 16.

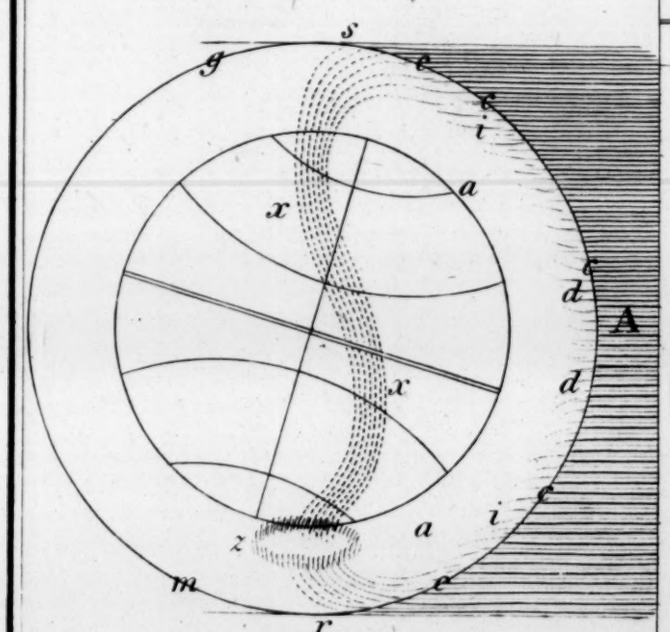
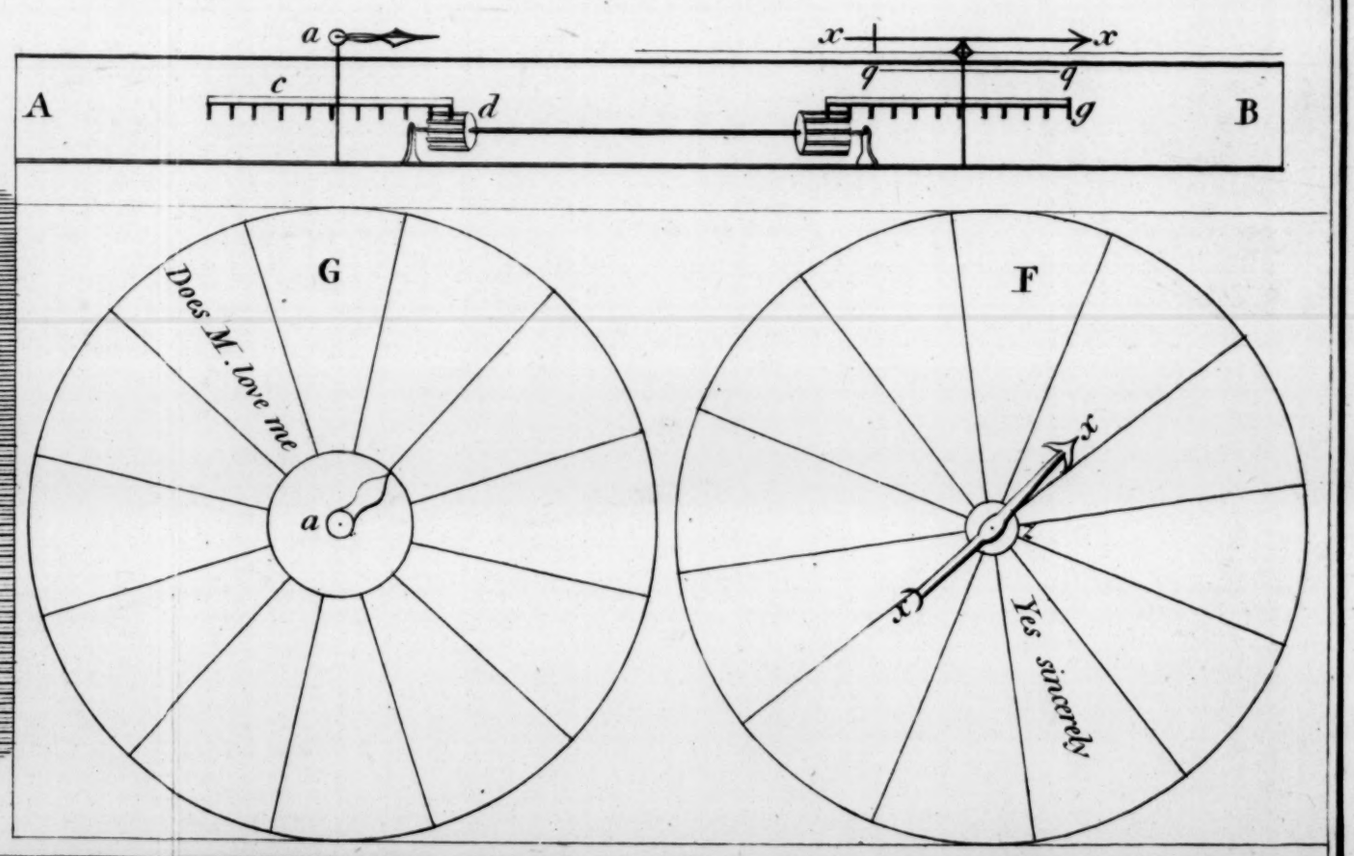


Fig. 18.



Barlow sculp

LECTURE III.

Mechanics.

SECTION I.

On Gravity.

IN the last lecture we endeavoured to give a general idea of the leading laws of nature; in this, its mechanic laws shall be more particularly considered. The attraction of cohesion, that wonderful power, by which the atoms of matter draw together, cohere, and maintain distinct forms, we hope was fully explained. But this principle is of much more extent and influence than appeared in that lecture; for we have many proofs to offer, that gravitation itself is but the attraction of cohesion upon a larger scale. By gravity, we mean that tendency all matter has towards the earth's centre; it is weight; and has been supposed to arise from an attracting something placed at the centre. But the following experiments tend to prove, that the whole globe itself is the attracting body, and not any thing placed at its centre. A pound of lead, and 200 yards of packthread, were put in one scale of a balance, and the same weight of lead and length of packthread were put in the other scale—they balanced each other. But when

one of the plummets, suspended by its 200 yards of packthread, was hung in the shaft of a coal-pit, of that depth from its scale, they did not balance each other; that in the coal-pit was lighter. Now as the air is more dense at the bottom of such a pit, than at the top, it is natural to suppose its greater buoyancy might occasion the difference; but when allowance was made for that, still there was found a want of weight in the suspended plummet, that could not be accounted for, but from the attraction of the 200 yards mass of earth above it. This mass certainly bears but a trifling proportion to the mass below it; but its attraction (on account of its vicinity to the plummet) will be seen hereafter to be a sufficient cause for the loss of weight in the plummet.

2d. A mountain was selected in this island, for the purpose of suspending the plumb line of a zenith sector, from the top of an high precipice. The plummet evidently inclined towards the mountain, out of a perpendicular. The same experiment was made over a similar precipice, on the other side of the mountain; and still the plummet was found to be attracted towards the mountain. Do not these experiments shew the whole body of the earth to be the attracting body, and the cause of weight? This mighty principle forms the earth into a round and dense ball, holds every thing animate and inanimate to its surface, and makes its whole surface its general top! By this do we stand fast on all sides of the globe; for the thickest mass of earth is directly under our feet, wherever we stand; and the thickest mass has the most powerful attraction, acting upon all bodies according to this law. If I let a stone drop from my hand, I say it is the attraction of the earth, that draws the stone to the earth. But if I let a stone drop from the top of St. Paul's cupola, I find it is accelerated in its descent,

going faster and faster; *i. e.* it will fall about 16½ feet, or a rod, in the 1st second of time; it will fall three rods in the 2d second; five rods in the 3d second; seven rods in the 4th second, &c. agreeable to the odd numbers 1, 3, 5, 7, 9, 11, 13, 15, &c. Why should the body be accelerated?—The power of gravity is as great on the top as on the bottom of St. Paul's; nay, we find little difference in this power, between the tops of the highest mountains, and the deepest pits. There is a principle Newton calls *vis inertiæ*, which, I think, clearly explains this; but let us first enquire what it is. Every one must observe a sluggishness in all kinds of matter; that when it is at rest, it endeavours to continue at rest; and when in motion, it inclines to continue in motion. No doubt, if I lay a ball on the ground, it would lie there for ever, if something did not put it in motion: and if I kick it with my foot, it would run or fly for ever, if there was no impediment to stop it. If I push a bowl of water with my hand, the water flies over the edge of the bowl upon my hand; for it endeavours to continue in the state of rest it was in. But if I take up the bowl, and running away with it, stop of a sudden, the water flies forward the way I was running; from its *vis inertiæ*, or tendency to continue in the state of motion it was in. Hence the difficulty of putting heavy bodies into motion, and the difficulty of stopping them when in motion. Why do I run my head through the fore glass of my carriage, when it accidentally runs against a post? My body is subject to the same law, as the most inanimate matter; and endeavours to continue in the state of motion I was in, before the carriage struck the post. The word *endeavour* applied to inanimate matter, calls forth the feeble criticisms of minor philosophers; but certainly all that was meant by it by the great Newton, was what we may see every moment, viz. the *tendency that all matter has to*

continue in the state it is in, whether of rest or of motion. But how is this *vis inertiæ*, you'll say, to account for the accelerated descent of falling bodies? If it is the power of gravity that pulls the ball from the top to the floor of St. Paul's, let us suppose that gravity to cease, just when the ball had fallen half way: now the quantity of motion it had acquired in that descent, would carry it forward, though gravity had ceased, by its *vis inertiæ*, or endeavour to continue in that state of motion it was in. As this law, like gravity, never sleeps, this power must operate upon the falling body every inch of its descent, and of course increase its motion. The air forms a resistance to the falling body; and, therefore, under any other retardation, no doubt the same rule will hold good: for if the air will not suffer a ball to fall farther than a rod in the first second of time, water would hinder it more; but if it falls an inch in any medium, or under any retardation, in one second, it will fall three in the next, five in the next, seven in the next, &c. as may be proved by hanging two balls, of unequal weights, by a long thread over a pulley; for by the slowness of the ball's descent the resistance of the air may be considered as nothing. The pulley should rest on friction wheels, as Fig. 1, to render the friction as little as possible. If now the heavier ball *a*, have its centre brought even with the top of the scale, and the pendulum *c* be drawn on one side, till the loose hammer *d* strikes the bell *o*, and both the ball and pendulum be let go at that instant, then will the ball *a* strike the stage marked 1, at the same instant the hammer strikes the bell *n*; shewing that it falls one in the first second of time. If now the stage 1 be taken away, and the ball and pendulum be put in the same position as before, and let go at the same instant, there will be a second stroke on the bells, the instant the ball *a* strikes the stage 3; or, in other words, there will

be two vibrations of the pendulum while the ball has fallen four, the square of that time. If now the stage 3 be taken away, and the pendulum and ball be put in the same position as at first, the bells will strike three the instant the ball strikes the stage 5, &c. shewing the ball to have fallen through nine spaces in three seconds, and that the fall of bodies is as the squares of the times; and which may be well represented by the endless triangle, Fig. 2, *a* 5 *b*, where 1, 2, 3, 4, &c. represent the times, or returns, of the second pendulum, *e c*, Fig. 1; *a* 1 *c* representing the space fallen through in one second of time; 1 *c d* 2, the space fallen through the 2d second of time, viz. 3; the space 2 *d e* 3, that which is fallen through in the 3d second of time, viz. 5; &c. So that we find another corroboration of the idea, that the squares of numbers was in the Almighty Mind at the creation of all things. Here we find at the end of the 3d second of time the ball has fallen nine. At the end of the fifth second, it has fallen twenty-five. At the end of the ninth second, it has fallen eighty-one, &c. the squares of the times.

This law equally holds in the fall of projected bodies. If I throw a stone horizontally, it falls to the ground in a curve of the parabola, and as fast as if I let it drop from my hand; and by the same rule as the foregoing. It seems a bold assertion to say, that a cannon, discharged horizontally on the top of a tall tower, shall throw a ball two miles distant; and that it shall strike a level plain, or the ground, at the same instant that another ball, let fall from the muzzle of the gun (the moment of its discharge), shall strike it! But there is no doubt of the fact; for though the projected ball may move point blank (and bid defiance to the power of gravity half its way), it will perform *that half* in so short a space of time, that

it will fall a rod in the 1st second, as from *a b*, Fig. 3; three rods in the 2d second, like all other falling bodies; for an horizontal impulse retards not the power of gravity, in respect to time. I have a groove in the board *a*, Fig. 4, from *b* to *c*; it is made cycloidal, as being the line of swiftest descent; down this groove, I let fall a child's marble, and it flies through the rings *d*, *f*, *g*, describing the semi-parabola *c r*. But at *c*, the ball strikes a feather which lets fall the ball *q*; the balls *r* and *q* strike the horizontal level *s r* at the same instant.

This may be still more mechanically represented by Fig. 3; for as bodies that are acted upon by two contrary or oblique forces, obey neither; so, as above, we see the power of gravity endeavouring to pull the ball down to the ground, while the gunpowder impels it horizontally; it obeys neither, but a medium, or diagonal of the two. Let *a* represent the gun, *c d* the horizontal distance, or the power of the gunpowder in the first second of time; *c e* the power of gravity; the ball obeys neither, but describes the diagonal, or medium, *c g*. When at *g*, the impulse of the powder would force it along the line *g h*; but counteracted by the power of gravity, it falls down to *n*, &c. thus falling in the above ratio, 1, 3, 5, 7, 9, &c. while the retardation of the ball by gravity, and the resistance of the air, is represented by the numbers 10, 9, 8, 7, 6, &c. This proposition, though the foundation of the art of gunnery, is not strictly true. Robins has found the states of the air, the differing strengths of gunpowder, and other circumstances, take off a little from its correctness, though the theory is strictly just; as will be seen, when we apply this sublime law to the explanation of planetary motion. Bodies thrown upward, are retarded in the same ratio as they are accelerated in their descent: and it is a

pleasing circumstance, to see how the greatest and the least things in nature are regulated by the same simple laws! Is it not wonderful, that the same law which brings the stone to the ground, which I throw from my hand, should be that by which the most magnificent of all machines is regulated, viz. the solar system. If *A* represent the earth, and *B* the moon, Fig. 5, and we find that her orbit *N* is an oval, or rather made up of curves of the parabola, and that she falls from a tangent, *B r*, to her orbit, agreeable to the odd numbers 1, 3, 5, &c. we cannot doubt but she obeys the same law as the common projectiles on the surface of the earth.

1st. That bodies which are acted upon by two or more forces, obey none of them singly, but a medium of all the forces, is provable in many familiar instances. Let *a* be a billiard ball, Fig. 6, and struck by two cues, *b* and *c*, at the same instant; *b* would impel it in the line *e*, and *c* in the line *d*; but both will impel it along the line *f*, the diagonal or medium between *d* and *e*.

2d. If a leaden ball be dropt from the mast-head of a ship, under swift sail, one would think, before the ball would reach the deck, the ship would be slid from under it, and that it would fall behind the ship into the sea. This is not the fact; for the ball falls down by the side of the mast, as if the ship was at anchor. Why? Because the ball is under the influence of two forces; one horizontal, by the motion of the ship; the other perpendicular, by the power of gravity: so that though it appears to fall perpendicular, it does not, but describes, in space, the same kind of semi-parabola as the aforesaid ball shot from a gun.

3d. If I throw a log of wood into the Thames, when the wind is across the river: the log will not obey the current, by going down the river, nor the wind, by going across the river, but a sloping direction made up of the two.

Pendulums obey the power of gravity reciprocally, as the square roots of their lengths; *i. e.* a pendulum four times as long as another, will vibrate half as fast; and one nine times as long as another, will vibrate but one-third as fast, &c. whatever may be the weight of their bobs. If the bob *a*, Fig. 7, be suspended by the thread *a b*, and let go at *a*, it will fall to *d*, and rise to *c*. This is called an oscillation. At *d*, the bob will have acquired the same velocity, as if it had fallen perpendicularly from *g* to *d*; and that quantity of motion will carry it up to *c*, by the forementioned law of *vis inertiæ*. In this are it would move for ever, but for the friction at the point of suspension *b*, and the resistance of the air. Hence pendulums become so useful in measuring time; for a pendulum of 39.2 inches, will vibrate an aliquot part of the time the earth is in turning upon its axis; *i. e.* $\frac{1}{86400}$ part; or make sixty oscillations in a minute. When we say that a pendulum of 39.2 inches will vibrate seconds, this must not be understood as holding good in all parts of the world: every thing grows lighter as we approach the equator, and heavier as we approach the poles, from the greater centrifugal force at the equator (occasioned by the diurnal rotation of the earth), which, according to some, is equal to $\frac{1}{289}$ part of gravity. Hence a pendulum of 39.2 inches would vibrate too slow near the equator, and too fast towards the poles. And as we have seen, by the pyrometer, that metals expand by heat, the rods of pendulums grow longer in the torrid zone: contributing also to the irregular going of clocks and time-keepers.

The length of a pendulum is from its point of suspension to its centre of oscillation; which centre is near the centre of gravity of the bob, if the rod be very light. But if a rod of equal thickness, *c d*, Fig. 8 (without a bob), be made a pendulum, its centre of oscillation is at two-thirds of its length from the point of its suspension; and it will vibrate in the same time as the pendulum *a b*, Fig. 8. The quantity of motion in the part *c e*, being equal to that of *a b*, if the point *e* be stopt by any obstacle, the whole motion of the rod will be stopt at once. Hence the centre of percussion in weapons, being the same as the centre of oscillation, it becomes easy to know where the stroke would have the greatest effect.

From this rod, a national standard measure might be constructed; for a rod of 58.8 inches will vibrate seconds; but if it were the thousandth part of an inch longer or shorter, it would not vibrate seconds. Here then is an invariable and eternal standard; and why might not 58.8 inches be an ell, a yard, a fathom, or any other name? and a quarter of it, the depth and diameter of a bushel?

We say that all bodies have a centre of gravity, or a point, on which they may be suspended in every direction. We consider the whole weight of the body, as if it were condensed or concentrated in that point: if this point, therefore, be supported, the whole body will be at rest; if not, it will always endeavour to fall the nearest way towards the centre of the earth. I endeavour to balance my cane upon my finger; after some time, I find a place where neither end will preponderate; the part which rests on my finger is its centre of gravity.

2d. I place the piece of wood, Fig. 9, on the edge of a table, and from a pin at its centre of gravity *a*, I hang the plummet *d*; the line of direction *a d*, passes within the base or foundation; and therefore the body does not fall, though it leans over its base.

3d. *The centre of gravity always endeavours to get beneath the centre of suspension.* I hang the above piece of wood on the pin *g*, Fig. 10, and on the same pin the plummet *d*; the line of direction still passes over the centre of gravity *a*.

4th. Hence the centre of gravity, of any regular or irregular plane figure, is easily found. Suppose the piece of board *A*, Fig. 11, be suspended freely on a pin from the hole *a*, and on the same pin be hung the plummet *a c*, and its direction be marked on the board. Now remove the pin and plummet to *d*, and then the board will hang as Fig. 12, and the plumb-line *d e* will cross the first line *a c* at *g*, which is the centre of gravity of the board *A*.

In the motion of a chain-shot, if one ball be heavier than the other, they will perform a circuit round each other as they fly; but their centre of gravity will describe a regular range, which will be a semiparabola. So the earth and moon, though they fly round each other in their annual journey round the sun, neither of them describe a regular oval round him: it is their centre of gravity that performs the real orbit.

5th. The tower *s a*, has its centre of gravity at *a*; a plummet *c*, let fall from it, and falling within the base, shews it will stand firm: but if *b* is placed upon it, the centre of gravity will be raised to *s*,

and a plummet let fall from it, falls without the base; so they will both fall.

6th. The tower of Pisa, Fig. 15, leans sixteen feet out of the perpendicular; strangers are afraid to pass under it. But if its materials will hold together, there is no fear of its destruction; for let a plummet *c*, fall from its centre of gravity, and it will be found to fall *within its base or foundation* (the steeple being nearly of the same thickness from bottom to top, and of course having the centre of gravity in the centre of the steeple); therefore it is no miracle, why the steeple has stood 300 years, and may stand 300 more. Two towers at Bologna, one at Corfe-Castle, one at Caerphilly, in South Wales; a wall at Bridgenorth, and an hundred more, all astonish the vulgar; who conceive they must be kept up by some supernatural power! Not at all. There is nothing (well authenticated) that is supernatural in the order of the world. Nature is uniform in all her works; and it would be happy for mankind, if when they are amused with feats beyond nature, they would look out for cheat and imposture. But unfortunately, the common kind of mortals are not yet weaned from the cheats, political and religious, that have fettered their minds, and those of their ancestors. Would to God I could say, this ignorance shewed itself only in leaning towers and old walls! Then, indeed, the mischief would be trifling; but when we see these towers and old walls really tumbling about our ears, and lose all sensibility of our danger, what a state of apathy must the mind have sunk to!!! Philosophy repels politics; they are oil and water!—they are fire and ice!—they detest each other!—for philosophy and deception hold no fellowship: truth is the goddess of her adoration, and she despises whatever leans to deceit or intolerance.

The difficulty of sustaining a tall body upon a narrow foundation, is evident, when I attempt to balance my cane with its end on my finger, Fig. 16; *a* is its centre of gravity; now if I have not dexterity enough to keep the foundation on my finger, perpendicularly under the centre of gravity, the stick must fall. Hence arises the difficulties of the equilibrist. This artist holds a long pole across the rope on which he dances, with great weights at each end, and keeps his eye upon some object parallel to the rope; by which he can see when his centre of gravity is on this or that side of his slippery foundation, the rope; and by pushing his pole on this or that side, he can keep his centre of gravity over the base.

7th. If a cylinder of wood, like a drum, with its centre of gravity at *c*, be placed on the inclined plane *a b*, Fig. 13. It will run down the inclined plane, because that centre leans over the base *g* during its descent. But if I fill the hole *n* with a plug of lead, the cylinder will roll up the inclined plane, till the lead gets near *g*; and then the cylinder will be in a state of balance, and lie still on the inclined plane. Because the centre of gravity is removed from *c* to *n*, by filling the hole *n* with lead.

8th. The double cone rolls up two parallel wires, though one end of them is considerably higher than the other, as Fig. 17. But the centre of gravity of the cone is really at *a*, higher than at *c* and *d*. For as it rolls, it sinks in between the opening wires, and is in reality descending, though it seems to ascend.

9th. The rolling candlestick, Fig. 18, keeps the candle always upright, though rolled over a floor; for a weight *a*, beneath the

candle, and also lower than the two centres of suspension, *c c* and *d d*, will keep the candle perpendicular; for the centre of gravity always endeavours to fall beneath the centre (or centres) of suspension. The circle *d c d c* hangs on two pivots, *e* and *f*; and the inner circle *o n* hangs on that circle by the pivots *d d*, at right angles to the pivots *e* and *f*. These circles are called jimbals by seamen; and the compass being hung on the inner circle, keeps always horizontal, notwithstanding the rolling of the ship; by which the magnetic needle can traverse as freely as if its point of suspension were fixed on shore.

10th. The nearer the centre of gravity and the line of direction coincide, the firmer any body stands on a plane. I stand firmer with my feet a little asunder, than if they were close. I lean forward when I have a load on my back, and backward when I have it on my breast. When I rise from my seat, I lean my body forward, and draw my feet back; in all these cases to bring the centre of gravity of my body over the base, my feet.

As the removal of great weights (or overcoming the force of gravity) is one of the great objects of mechanics, it is now time we should explain the six mechanic powers, by which this and other difficulties are overcome. But we should first be instructed in the momentum, or moving force, of machines or bodies.

1st. If the roller *a*, Fig. 18, lean against the obstacle *b*, it will be found incapable of overturning *b*: but if *a* be taken up to *c*, and suffered to roll down the inclined plane against *b*, it will overturn it. We call the stroke with which *a* strikes *b*, its momentum;

and that momentum is the quantity of matter in *a*, multiplied by its quantity of motion.

2d. We perform, in our days, greater feats with a small bullet, than the ancients did with their huge battering ram. Suppose the ram, Fig. 19, to be 27,360lb. weight; and, being suspended by its centre of gravity *a*, from the support *b*, that it could be influenced by manual strength to move against the wall *K*, at the rate of one foot in a second of time; then its quantity of matter multiplied by its motion, would be $27360 \times 1 = 27360$, its momentum. Now if a bullet *c*, of 24lb. weight, be shot out of the cannon *g*, the ball will go as swift as sound; and that is 1140 feet in a second of time; so its quantity of matter, viz. 24lb. being multiplied by its velocity $1140 \times 24 = 27360$, its momentum, or moving force against the wall *K*. These two momenta being equal, their effect against the enemy's wall or gate must be equal; and shew that bodies may make out by quantity of motion, what they want in quantity of matter, and *vice versâ*.

3d. *If a body falls upon any plane, from the height of about one inch and a quarter, it will strike the plane with a momentum, equal to double its weight.* I immerse the stick *a*, Fig. 20, in a tall vessel of water; and upon the wire *b*, I slip two brass balls, each one ounce; by their weight they will sink the stick, so that the pin *c* stuck in it will just touch the edge of the vessel. I now take off one of the balls, and the stick rises out of the water a little: the remaining ball being then lifted up to *d* (one inch and a quarter above the top of the stick), and let fall on the stick, it will sink it so much, that the pin *c* will just touch the top of the

vessel, as when both balls were on the wire. This experiment is made in water, to prevent friction.

4th. It is equally so with the heaviest bodies: if I lift one hundred weight from the floor, one inch and a quarter, and let it fall, it will strike the floor with a momentum, equal to two hundred weight, &c. Hence may be calculated the momentum of any falling body from any height, as shells, pile-drivers, strokes of hammers, &c. for as the laws of nature seem to be regulated by the squares of numbers, if a falling body acquires a momentum, equal to double its weight in falling one inch and a quarter, it will have twice that effect if it falls four times as high; three times that effect if it falls nine times as high, &c. &c. Let the light scale-beam *c d*, Fig. 21, have a hole at *c*, and a hook at *d*; let a wire *g* pass through the hole, and be fastened to the ceiling of the room, tight. If this wire goes through one of the above brass balls, as *d*, and it be let fall on *c*, from an elevation of one inch and a quarter, it will lift two ounces at *d*, and let go the slight spring *o*. If now two ounces more be hung on *d*, as *w*, and the ball *d* be let fall five inches, it will lift both weights, as will be proved by its disengaging the spring *o*. If then the ball *d* be let fall $11\frac{1}{4}$ inches, it will lift three of the weights at *d*. If let fall twenty inches, it will lift four of those weights; four times four making sixteen, &c. &c. agreeably to the square root of the heights.

5th. If I drop a ball into a pot of honey, and it sinks to a certain depth in the honey, and then let it fall four times as high, it will sink twice as deep in the honey; nine times as high, and it will bury itself three times as deep in the honey, &c. &c.

6th. If a shell of 50lb. weight were to fall from an height of seventy yards, according to these calculations, it would strike the ground with a momentum equal to 4600 pounds.

7th. If a stone in the road resists a light carriage, with a force equal to one pound; if the carriage runs four times as swiftly over it, the same obstacle will form a resistance equal to two pounds; if nine times as swift, the resistance will be equal to three pounds, &c. &c. I speak here of a light carriage, because an heavy one, when put in motion, has a *vis inertiæ* that will carry it over any trifling obstacle, without any additional draught. This must also be understood of carriages that move with great velocity; for in waggons, the slow motion obliges the horses to overcome their *vis inertiæ* every moment of the draught; or, as if the waggon were taken out of a state of rest every moment, into a state of motion. Hence swiftness takes off greatly from draught; and if that swiftness did not fatigue horses as much as draught, they would have less to draw the swifter they *went*.

Percussion, or collision, is but an illustration of that general law, that *action and reaction are equal*. If I strike an anvil with a hammer, the anvil strikes the hammer as forcibly as the hammer strikes the anvil. If that anvil be large enough, a man may lay it on his breast, and suffer a strong man to strike it with a sledge hammer with all his might, without the least pain or danger; for the *vis inertiæ* of the anvil resists the force of the blow, and the man does not feel it. But if he had an anvil of no more than a pound weight on his breast, such a stroke would kill him.

2d. Let *a* be a little cannon, Fig. 22, and *b* a hollow piece of

iron or brass, to slip on pretty tight upon *c c*, and of the same weight as *a*. Now if half a thimblefull of gunpowder be put in *a*, and *b* shut upon it, both being suspended by strings; if the powder be fired, the parts *a* and *b* will be thrown equally distant from *r*, the centre where they hung; shewing the reaction to be equal to the action. Hence an heavy gun seems to recoil less than a light one, on account of its greater *vis inertiæ*; otherwise its reaction is the same, with the same charge.

3d. Let two ivory balls be suspended by threads, as Fig. 23; if *a* be drawn a little out of the perpendicular, and let fall upon *c*, it will lose its motion by communicating it to *c*, which will be driven to an equal distance to what *a* fell, viz. to *o*. By laying a little paint on *a*, if it touches *c*, it will make a small speck upon it: but if it *falls* upon *c*, the speck will be much larger; shewing the balls to be elastic, and that a little hollow or dint was made in each by their collision. These hollows being equal, their reaction must be equal, pressing both balls alike in contrary directions. Therefore the ball *a*, imparting its half to *c*, will give *c* (with its half) the same momentum as *a*, and drive it to the same distance *o*; while *a* loses by the action and reaction its momentum, and becomes stationary. So if two soft clay balls met each other with equal velocities, they would stop and stick together at the place of their meeting, as having no elasticity.

4th. But of three elastic balls, *c*, *a*, and *n*, hung from three adjoining centres; if *n* were drawn a little out of the perpendicular, and let fall upon *a*, then would *n* and *a* become stationary, and *c* be driven off to *o*, the distance *n* is from *a*. Fig. 24.

5th. From the same elastic cause, if eight balls (or any other number) were hung so as to touch each other; if the outside ball were drawn off a little distance, and let fall upon the other seven, the ball only on the opposite side would be driven off, while the rest would remain stationary; so equally is the action and reaction of the stationary balls divided amongst them. Fig. 25.

6th. If two of the above eight balls were drawn a little on one side, and let fall on the other six, the two outside opposite balls would be driven off as far from the rest as the two first fell, while the other six remained stationary. Fig. 25 and 26.

SECTION II.

The Mechanic Powers.

COMPLEX as many machines may appear, they are only made up, more or less, of six mechanic powers, viz. the lever, the wheel and axle (or axle in peritrochio), pullies, inclined plane, the wedge, and the screw.

A lever is a bar of any shape, long, short, round, square, flat, taper, &c. It is used to raise great weights a small distance, and is of three kinds. The lever of the first kind has its fulcrum between the weight and the power, as *F*, Fig. 27; the end of the lever *t s* being supposed a balance for the other part of it, *s r*. From *s* to *t* is called the acting part of the lever; and from *s* to

r the resisting part of it: and it is as the acting is to the resisting part, that we gain an advantage over the body to be lifted; *i. e.* if the acting part *s t*, be four times the length of *s r* (estimated from the fulcrum *s*), then will 1lb. hung at *t* balance 4lb. hung at *r*. Consequently I could lift four times as much with this lever, as I could by main strength. A scale beam is a lever of this kind; its centre *c* is the fulcrum, and the spot *n* its centre of gravity; and the nearer the centre of gravity and the fulcrum can be brought together, the nicer and more delicate will be the beam. Now, if two equal weights, *s* and *t*, Fig. 28, be hung at equal distances from the fulcrum, they will balance each other, and the beam will be at rest; because the centre of gravity, of the beam and weights, is now at *o*, directly under the point of suspension. But if *t* were removed to *a*, then the centre of gravity would not be under the point of suspension *c*: and as it is a law of nature, that the centre of gravity always endeavours to fall or get beneath the centre of suspension, or as low as it can, hence we see the reason why that end of the beam preponderates; and why a small weight hung at *a* will balance the great weight *s*. On this obvious principle hangs the whole doctrine of mechanics; for we only substitute time or motion in the place of power, in all machines intended to assist animal strength. For if I apply my weight at *a*, and can lift four times that weight at *s*, I shall descend at *a* four times the distance that the weight *s* will rise. For if one man can raise by a machine as much as ten men could by main strength, he will be ten times as long about it. If *s*, therefore, be 8lb., 2lb. at *a* will balance it, and the beam will be in equilibrio; for the momenta of the two arms, their weights, and motions, are exactly so. Suppose, then, that the weight *a* hangs twelve inches from the fulcrum *c*, and we call that its motion; this being multiplied by its weight,

2lb., gives twenty-four for the momentum of the arm *c a*. Now the weight *s* must hang three inches from the fulcrum *c* to balance *a*, for three times eight makes twenty-four, as well as two times twelve; so the two arms balance each other, like the Dr. and Cr. sides of a merchant's ledger. On this principle depends the steel-yard, Fig 29, where if *a* hangs ten times the distance from the fulcrum *c* that *b* does, then will *a* balance ten times its weight at *b*; and if put into motion, will move ten times as far. This lever may also be multiplied, so as to become infinitely powerful. Suppose at *a*, Fig. 30, there hangs 27lb., and that the acting part of this lever, *b c*, be three times the length of its resisting part, *b a*; in that case (agreeably to what has been proved), 9lb. of strength applied at *c* will balance the 27lb. hanging at *a*, being one-third of it. But to overcome the said 9lb. I apply the lever *o d*, of the same acting and resisting powers as the last; so that 3lb. of strength applied at *d*, will balance the 9lb. at *o*. But not satisfied with this, I apply another lever *r s*, whose acting is to its resisting part as three to one, as before, to overcome the 3lb., and reduce the power to 1lb. So that 1lb. hanging at *s*, will balance 27lb. hanging at *a*; and if put into motion, will move twenty-seven times as far: still being only a substitution of time or distance in the place of actual power. The heaviest waggons are weighed by compounded levers of a similar principle. Handspikes move the heaviest guns; and the largest trees are torn up by the roots; as thus, Fig. 31;—a strong scantling is fixed on the strong axle of the cart-wheels *c*; it is then tied to the tree at *r*; when the lateral roots of the tree are cut, by digging a trench round it, the tap roots are easily torn up by a team of two or three horses; for the tree itself becomes the lever, and the axle of the wheels its fulcrum; which wheels become a carriage for the tree to the place where it is to be transplanted.

Plyers, pincers, scissars, hammers drawing nails, &c. are all levers of this kind.

The lever of the *second kind* has its acting and resisting parts on the same side of the fulcrum, as *a b*, Fig. 32; *a b* is the acting, *b c* the resisting, part of this lever; and as the acting part is four times the length of the resisting, 1lb. hanging over a pulley at *a*, will balance 4lb. hanging at *c*.

This is the principle of a wheel-barrow: *b* may be considered as the wheel, which is the fulcrum, *c* as the load, *a* as the hands of the labourer. Hence the reason why a man can carry two, three, four, &c. times the weight in this machine, he can by main strength.

A four-wheel carriage is a lever of this kind. If the centre of gravity of the load be half way between the fore and hind wheels, then will the acting part of the lever be twice the length of the resisting, as Fig. 33. For when the wheel *a* comes to the obstacle *c*, there will be but half the weight of the load to pull over it, because the acting part of the lever *a b* is twice the length of the resisting part *b o*: it is true that when the hind wheel *b* comes to the obstacle, the other half of the weight must be pulled over it; for then the acting part of the lever will be *b a*, the resisting *a o*: in the first case *b* was a fulcrum, in the second, *a*. Though the sum of these two resistances is equal to what they would have been, had the load been on one pair of wheels, yet by the four wheels the difficulty being divided into two parts, gives a less check to the draught of the horses; and it is remarked, that nothing damps

the ardour of that spirited animal so much, as sudden jerks or checks.

A knife, moving from an hinge at one end, as *a*, Fig. 34, is a lever of the second kind: if from *a* to the handle *b* be four times as far as from the fulcrum *a* to the wood to be cut at *c*, then with such a knife I could cut the wood with four times less exertion, than by a common knife of equal sharpness.

The lever of the *third kind* has its acting part shorter than its resisting part, requiring more exertion than would be necessary to lift the body by main strength; like rearing a ladder against a wall, or holding my cane (at one end) horizontally between my finger and thumb. Fig. 35 will explain it better; *a* is a weight to be lifted by the weight *b* pulling at *c*, over a pulley; *d* is the prop, or fulcrum. Now as the acting part of the lever, *d c*, is but one-fifth of the resisting part, *d o*; therefore *b* must be five times as heavy as *a*, or it will not balance it.

Of this sort of lever are the limbs of all animals. My arms, legs, fingers, are such. The legs of quadrupeds, the wings of birds, and the fins of fishes.

The bone from my shoulder to my elbow is single; that from my elbow to my wrist double; (for the wise and useful purpose of turning in every direction). From the shoulder-blade *c*, there are two muscles that terminate a little below the elbow at *e*; by the swelling of which (as at *d*), the arm or lever *n o* is enabled to lift the weight *s*. So that the bones *n o* are represented by the

lever *d o*, in the last figure; the weight *s*, by the weight *a*; the elbow *n*, by the fulcrum *d*; and the muscle *c e d*, by the weight *b* pulling at *c*. Hence if the distance *n s* be six times the length of the acting part of the lever *n c*, and the weight *s* be 10lb., then must the contraction of the muscles at *e*, be equal to six times 10lb., or 60lb! Why has nature assembled such a quantity of muscles in the calf of my leg? Because I was to lift my whole body, and walk by them. To push myself forward in walking, it was necessary that the resisting part of the lever, from my ancle to my toes, should be much longer than the acting part, from my heel to my ancle, to have more scope on the ground; and that the contraction of the muscles need not be too great. Accordingly, the foot, considered as a lever, has its acting part very short, and put in motion by the *tendo Achillis*, a strong fibrous tendon attached to the heel, and ending in many ramifications among the muscles of the calf. It is a little mortifying to the pride of investigation, to think that a reason cannot be given why we can bend one of our fingers: we talk learnedly of the living, or sentient, principle of muscular motion and muscular irritability; but we know nothing on this subject after all! We know that limbs are levers; the coupling of the bones, fulcra; that they are moved at will by a commanded muscle or muscles; but what is it that informs those muscles? There we stop. The philosophy that has attempted to go farther, has hitherto been bewildered in obscurity, conjecture, and jarring opinions: the mind has launched into an ocean, seemingly without bottom or side; perhaps too wide and too deep for human faculties: for the few truths we seem qualified to attain, come best through the channel of the common senses. What we can see, hear, feel, taste, &c. we can reduce to experiment, observation, and compa-

rison; and from these form some probable conjectures, at least, what is their design in the general order of nature.

The wheel and axle, or *axle in peritrochio*, is the next mechanic power; and may be considered only as a number of levers acting round one general fulcrum, or the gudgeon or centre on which the wheel is suspended. A radius, or spoke of the wheel, being the acting part of the lever, and the radius, or semi-diameter of the axle, the resisting part of it. In Fig. 37, *a b* is the wheel, *c e* the axle, *d* the gudgeon or centre. So that *a d* (the radius of the wheel) is the acting part of the lever; and *d e* (radius of the axle) the resisting part of it: hence if *a d* be twice the length of *d e*, then 1lb. hung at *a* will balance 2lb. hung at *e* (agreeably to the doctrine of the lever); and shews that wheels are to their axles as their diameters, and what is gained in power is lost in time. This may be better understood by inspecting Fig. 38, where the axle in peritrochio is seen in profile.

Cranes for raising goods out of, or into, ships, warehouses, &c. are principally of this mechanic power; capstans, windlasses, &c. Cranes are of various construction: the wharf crane is sometimes moveable on a post fixed in the ground, as *a*, Fig 39, on which the machine and operator are both supported: a cogwheel, *c*, is fixed on the axle *o*, into whose teeth the pinion *d* works by the handle *b*. Now if the crank handle *b d* be five times the semi-diameter of the pinion *d*, then is the acting part of the lever five times the length of the resisting part; and I turn by this handle the wheel *c*, with one-fifth of the strength necessary to pull it round by its teeth. But the wheel *c* being twice the diameter of the axle *o*, this doubles the forementioned power; so that by these two powers I gain an ad-

vantage of ten; being able to raise ten times the weight I could by main strength, allowing for the friction of the machine. The pulley *r* only changes the direction of the draught, but gives no mechanical power. So the whole turning on the post *a*, the package *s* can easily be turned from the wharf over the ship, and let down into it.

The *capstan* has its power from the same principle; it is a long cylinder of wood, with holes in it for handspikes, like *a*, Fig. 40. The acting part of the lever is, therefore, from *c* to *d*, the resisting from *c* to *s*; (where the cable *n* is coiled round the capstan). Now if a man's weight be applied at *d*, and *c d* be ten times the length of *c s*, then will the rope *n s* pull ten times his weight, allowing for friction, which in the capstan is very great; as the centre on which it turns must be nearly as thick as the capstan itself, when a ship is to be held at anchor by it.

The *large circular crane* in which a man or horse walks, and which is actuated by his weight, is a cumbrous machine, and of trifling power. The man can seldom climb higher up the wheel than to *a*, Fig. 41, so that the line *c o* is the acting part of the lever, and *d o* the resisting part; now if *c o* be only twice the length of *d o*, then can the man raise only double his weight; allowing also for friction, and the *vis inertiæ* of this unwieldy machine.

The *windlass* has its axle generally beneath the surface of the ground, as *a*, Fig. 42, turning in strong and fixed timbers; it is actuated by radiant handspikes, as *s*, sometimes by men and some-

times by horses, coiling up the rope or chain *q*. Now if each handspike be ten times the length of the semi-diameter of the windlass, and there be eight handspikes, then $10 \times 8 = 80$, which is the power of this machine.

SECTION III.

Pullies.

THE SINGLE PULLEY, unaccompanied by other powers, is not a mechanic power, for it gives no mechanical advantage: it serves to change the direction of a draught; and it gives a man an opportunity of applying his weight, instead of his muscular strength: but in this way he can lift no more than his weight; and without multiplication, no machine is said to have mechanic power.

If two sheaves be in the block *a*, Fig. 43, and one in the block *b*, this assemblage will have a power of three; thus, fasten the rope to the lower block at *c*, and carry it over the nearer sheave in the upper block, then under the sheave in the lower block, and over the farther sheave in the upper: the end of the rope being now held by the hand at *n*, it is evident the weight *w* will be sustained by three ropes; and as all the ropes are equally stretched, of course each rope sustains one-third of the weight: now the hand *n* pulls but at one of the ropes, of course but at one-third of the weight; therefore the power of pullies, so systemized, *is as*

the number of ropes next to the weight, and the hand *n* will fall three times as far as the weight *w* will rise; shewing that what we gain in power we always lose in time or motion.

The weight *w*, Fig. 44, hangs by six ropes; and of course the power is six. But as the greatest stress is on the sheave *a*, over which the rope comes last (on account of the great friction in pullies), and as the centre of pressure, as well as the centre of gravity, always endeavours to get under, or in a line with, the centre of suspension, the stress on *a*, when the rope *c* is pulled, forces *a* under *b*, the centre of suspension; making the sheaves to rub so much against the block, as to make the friction nearly equal to all the power. This renders multiplication in pullies very limited; it is seldom that more than three or four sheaves can be used with convenience. But the late ingenious Mr. Smeaton obviated this objection, by making the fall, or rope, *c*, to come over the middle sheave instead of the outside one: by this means the block is kept perpendicularly under *b*, and the sheaves have no friction but on the centres on which they turn. This block, so useful for stretching the shrouds of ships, raising mill-stones, &c. may be easily understood, by a mere inspection of Fig. 45.

It may be seen in this pulley, that it must always consist of an *uneven* number of sheaves, as three, five, &c.; this consists of three large sheaves, and three smaller, in each block; they are made so that the ropes need not rub on each other, and occasion unnecessary friction. To reeve this block, we fasten the end of the rope to the upper block, as at *a*; then carry it under the first large sheave in the lower block; then over the first large sheave to the right hand in the upper block; then over the first small

sheave in the lower block to the right hand; then over the first small sheave in the upper block; then to the second in the lower; then to the second in the upper, and so through all the smaller sheaves; then to the first large sheave on the left hand in the lower block; then to the same in the upper block; then to the second in the lower block; and then end at the middle large sheave in the upper block.

The running block doubles whatever power went before it, thus: the weight *w*, Fig. 46, is sustained by the two ropes *a* and *b*; now if the rope *a* be fastened to any thing, and *b* be pulled at, the pull need be but equal to half the weight, because the rope *a* sustains the other half; so *c* is called a running block. But a system of running blocks may yet make the doctrine more evident. The weight *w*, Fig. 46, is sustained by the ropes *a* and *b*, each supporting one-half of the weight. Now if *b* be fastened to the crane *d*, then to pull at *a* would be to lift only one-half the weight *w*. But we will apply another runner to sustain *a*, by the two ropes *c* and *e*. Now if *e* be fastened to the crane, then *c* sustains half the weight of *a*, or one-fourth of the original weight *w*. But suspending the weight of *c* by the two ropes *o* and *n*, and tying *n* to the crane, then does *o* lift but half of *c*, or one-eighth of the original weight. The uppermost pulley only changes the direction of the rope, and adds nothing to the power. So that the lowest runner doubled the power, the next doubled that, and the next doubled the last, &c. &c.

Hence if the weight *w*, Fig. 47, be pulled at by the rope *a*, with its other end fixed at *b*, the pulley *c* doubles the power, being a running block.

THE WEDGE. This power is applied to cleave wood or stone; to separate heavy or cohering bodies; for even the largest ships can be raised by an assemblage of wedges. The power of the wedge is *as its length to the thickness of its back.* Let *a*, Fig. 48, be the wedge, *c* and *n* two cylinders, hanging by their centres from the beam *d*, and pulled against the wedge by the weights *r* and *s* (representing the resistance to be overcome by the wedge). Now if *s* influence *c*, and *r* influence *n*, with each a force of 2lb., then 4lb. will be the difficulty to be overcome: and if the length of the wedge be *twice* the length of the thickness of its back, then will it be found that the wedge and its weight, *o*=2lb., will balance the 4lb. of resistance; shewing that the stroke of a hammer = 2lb. would overcome 4lb.; or, that the power of the wedge is as the thickness of its back to its length.

This is true, where cylinders or bodies with little friction are to be separated: but where a blunt wedge is to penetrate a stone, or a piece of tough wood, a ton weight laid upon it would scarce force it in; when a smart stroke of a hammer, whose momentum was not a quarter so much, would do the business. So whilst I vainly endeavour with all my weight to force a nail into wood, the smallest tap with a hammer will do it effectually. Perhaps the smartness of the stroke may derange the cohesion of the body, and by making a quick vibration among the particles, dispose them for separation. But if it be considered that the momentum of a hammer has both the velocity with which it moves, and its weight multiplied together, and these concentrated into a momentary force, it appears strange that its effects should be considered as a mystery.

THE INCLINED PLANE is, in reality, but a stationary wedge; by it we estimate the power necessary to drag carriages up-hill, the descending force of rivers, &c.; and its power (like the wedge) is *as its length to its height*. Let *a c*, Fig. 49, be an inclined plane, rising one foot in three; or whose length, *a c*, is three times its height, *a d*. Now, if a cylinder or roller *n* be 3lb. weight, 1lb., *o*, hanging over the pulley *r*, will be found to balance it; or, I should drag the weight *n* with three times less exertion up *a c*, than I could lift it perpendicularly from *d* to *a*: but, in this case, I move it three times as far; shewing, both in the wedge and inclined plane, that we only substitute time in place of power. This is the reason why roads should wind zig-zag up steep hills, to flatten the declivity, though it increases the length. The draught of a carriage of any weight, and on any kind of road, may be estimated by means of the inclined plane, thus: provide a board or box, *a b*, Fig. 50, capable of holding pebbles, mud, sand, &c. and which can be raised at one end by the screw *d*. When *a b* lies flat on *c b*, the carriage *n* will be at rest; the screw now raising *a b* leisurely, the carriage will, at a certain height, set off of itself, and roll down the plane. Here then are we in possession of a triangle, that solves what force is necessary to drag any load, on any kind of road, on level ground; for the hypothenuse *a b* represents the weight of the carriage, and the perpendicular *a c* what portion of that weight is necessary to draw the carriage on level ground. Suppose the carriage 12cwt.; the line *a b* = 24, and the height *a c* = 3: the declivity then is as 3 to 24, or as 1 to 8. In this case it will be found, that one-eighth of the weight of the carriage would drag it in such a road on level ground, viz. 1½cwt. But if the road was very deep or rough, the road might be raised, perhaps, as high as

s, before the carriage would set off. Now if *c s* was half the length of *s b*, then would it require one-half the weight of the carriage to drag it on level ground, or in the above case, 6cwt. This rule is universal, and has been proved by carriages at large, on roads of every description. In estimating the draught up-hill, the draught on the level must be added to it. Suppose the hill rises one foot in four; then one-fourth part of the weight must be added to the draught on level ground. If the weight (as before) be 12cwt. then one-fourth of it would be 3cwt. and its draught on the level was 1½cwt. these two make 4½cwt. the real draught necessary to draw 12cwt. up a hill rising one foot in four, &c.

THE SCREW is but an inclined plane, wrapt as it were round a cylinder, as *a*, Fig. 51; its power, therefore, is *as the length of its thread to its height*; or as the hypothenuse *c d* is to the perpendicular *c e*; or as the circumference of one thread is to the distance of the threads from one another. May not the lever, the wheel and axle, and the pullies, be all considered as only modifications of the lever? and, for the same reason, the wedge, inclined plane, and the screw, but as modifications of the wedge? May not, therefore, the screw, influenced by the lever, be considered as the quintessence of all mechanic power; and that there is, in reality, but two mechanic powers instead of six?

SECTION V.

On Friction.

FROM these calculations, however, considerable deductions must be made, for unavoidable friction, and the imperfect manner in which machines are generally made. Friction is said to be of two kinds, the rubbing friction, and the friction by contact: the first may be represented by a locked coach-wheel dragging on the road; the second by the wheel touching the ground in its usual motion. If the axles of wheels, the gudgeons of mills, and other parts that rub, be polished as well as possible, there will still be in them little eminences and little hollows, which, locking into one another, produce the impediment called friction of the first kind; *this* is, perhaps, the least when well polished iron and bell-metal rub on each other. Friction-wheels, however, do little good, except in machines whose rapid motion would set them on fire: in heavy machines they wear into notches, and are too liable to be out of order, to be useful. But the enormous stone in the grand square of Petersburgh, was moved on steel balls, Fig. 61. Bridges over canals frequently can be turned out of the way of boats, by moving on friction balls, Fig. 62. So the heads and sails of wind-mills, the domes of observatories, &c. can be easily turned on frames of friction-rollers; as well as the sheaves of common pullies, mangles, &c. Fig. 63, though straight, may represent a part of the round bottom of a dome; *a b* the wall plate; *c d* bottom of the dome; *e n* the frame going round the dome, containing the friction-rollers at proper distances from each other; on which a heavy

millhead, or dome, may be turned round by the hand. So in the pulley, Fig. 64, if the axle *a* be touched only by the friction-rollers (kept in a circular frame at a proper distance from each other), and the pulley *p* turn on their outside, three men are said to lift by this pulley as much as five with the usual one. The most usual mode of using friction-wheels is, as in Fig. 65, where the wheels *a* and *b* form a notch, for the axle *c* to turn in; *a* and *b* do not touch, but are very near one another, and turn on small pivots almost without friction. Two similar wheels being on the other side of the large wheel *N*, support the other end of the axle *c*. These are the usual applications for diminishing friction; and where it is not diminished by some of these methods, we generally, in machines consisting of three or more powers, allow *one-third* for rubbing, and imperfection.

A common crane will serve for an example, Fig. 66. We begin the calculation first with the crank-handle *a*, which is five times as far from the centre of the pinion *b*, as the teeth of the pinion; according to the principles of the lever, I gain five by this handle: the next power is the wheel and axle; the wheel *W* is made purposely to be twenty times the diameter of its axle *c* (round which the rope of the crane is coiled); by this power I gain an advantage of twenty: so five times 20 is 100, the power of the crank-handle, and the wheel and axle together; tracing the power along the rope *d*, it passes over the pulley *e*, which changes its direction, but gives no power. We then come to the weight *P*, which hangs by six ropes, but the axle *c* is pulling but at one of them; so this assemblage of pullies multiplies the former advantages six times; then six times 100 is 600, the *theoretical* power of the whole machine: and I should go with my hand (at *a*) 600

times as far as the package *P* would rise. But, by trial, I soon find I cannot raise 600 times as much as by main strength: the rubbing of the axles of the wheel and pinion; the contact of their teeth; the coiling of the rope; and the allowance for pullies of one-half for friction; altogether, one-third must be allowed for friction, and the imperfect manner in which machines are commonly made; so that instead of saying, according to theoretical calculation, I can by this machine lift 600 times as much as I could by main strength; I can, in reality, lift but two-thirds of it, or 400 times as much.

This crane is made in a variety of ways, both for convenience and force; and has generally the projecting part *x* to turn on a strong hinge at *e*, for the convenience of landing, shipping, or housing of goods.

Informed of our power, we can, by these means, easily calculate what that power can produce. A middle-sized horse can draw for eight hours in a day, with a constant force, equal to 32lb. What load can he draw upon a plain road? Suppose the declivity before the carriage sets off of itself to be one inch in 32 (see page 94), then 32 multiplied by 32, is 1124, or something more than 10cwt.

2d. A plough requires, in common land, 80lb. to draw it; hence two, and generally three, horses are yoked to it.

3d. I have a brook, with a sufficient fall, in my estate, that with penning will afford me 300lb. of water to act upon a wheel; but a millstone requires 600lb. force to carry it sixty times round in a minute (its proper velocity). I must in that case make the cog-

wheel (which overcomes the resistance) but half the diameter of the water-wheel: by this means I make 300lb. of power overcome 600lb. of difficulty.

4th. I want to raise a hundred weight of water out of a well, at one draught: the horse draws, in common, little more than 30lb., and that is contained nearly four times in 112lb.; so the wheel round which the horse's rope is coiled, must be nearly four times the diameter of the axle, round which the bucket rope is coiled, and the horse will draw it up with ease, walking straight forward.

5th. I want to drive piles into the ground, that require a ram of 15cwt.; what number of men must I hire to work it? A working man weighs, at an average, about 1½cwt.; so that ten men must be hired.

6th. I want to raise a stone to the top of a building of 200lb. weight, the rope to go over a pulley hung at the end of a projecting beam above the top, and to go under a pulley fixed in the ground; what number of horses will this require? In the first place these pullies give me no mechanic power; but rather add to the difficulty by their friction. If then a horse's power is 32lb. there is 6 times 32 in 200, so that six horses will be required. But for a sudden and short exertion a horse will exert twice the power he does in ordinary draught; upon such an emergency, therefore, three or four horses would do it.

From such considerations as these do we calculate the size of wheels, the length of levers, &c. for every mechanic purpose.

Fig. 5.

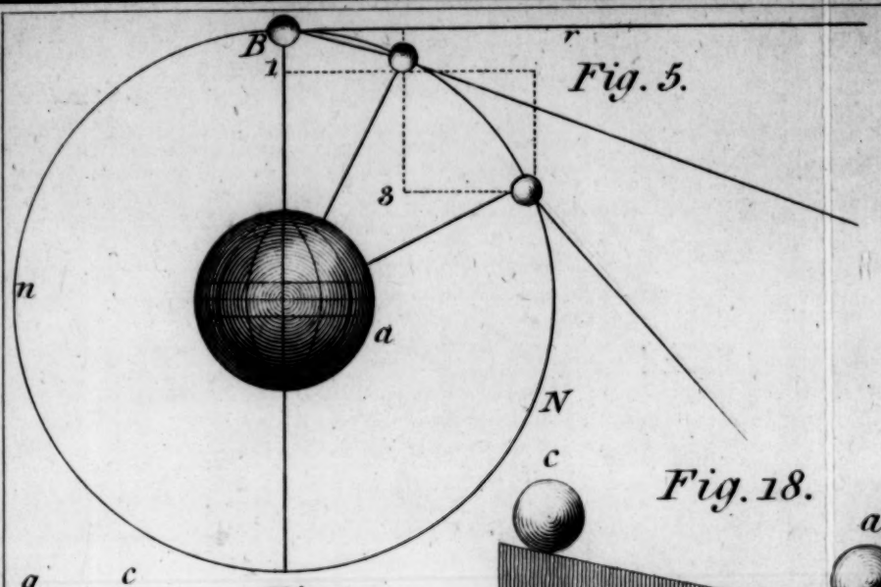


Fig. 18.



Fig. 4.

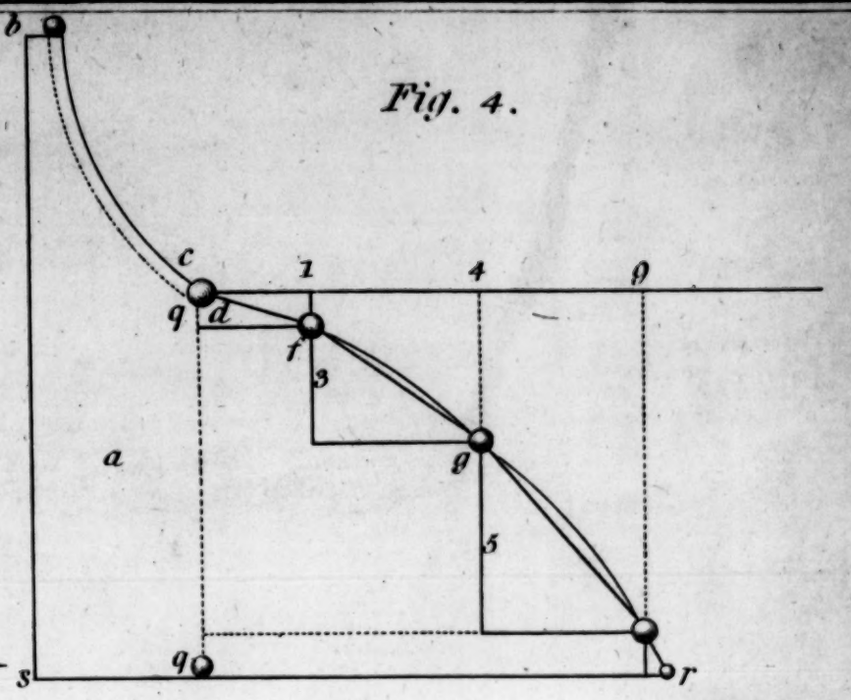


Fig. 9.

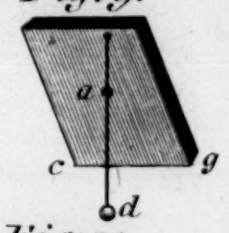


Fig. 16.



Fig. 6.

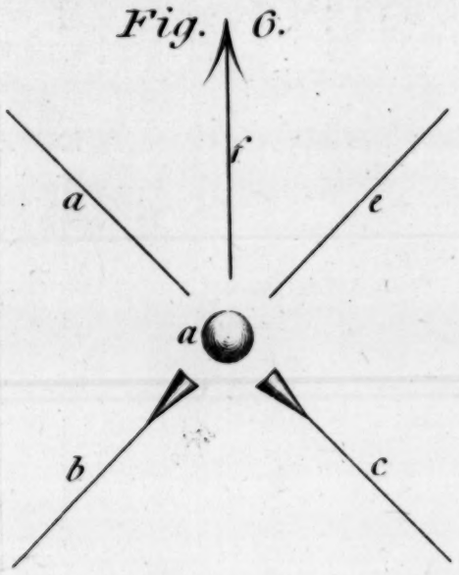


Fig. 10.



Fig. 8.

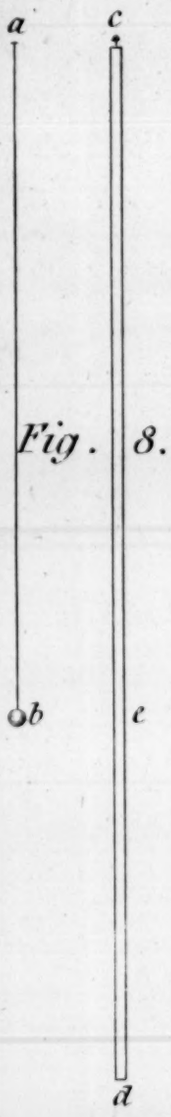


Fig. 11.

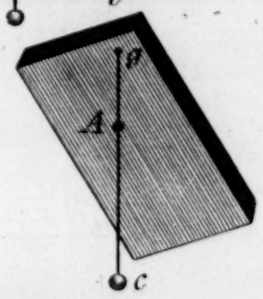


Fig. 12.



Fig. 17.

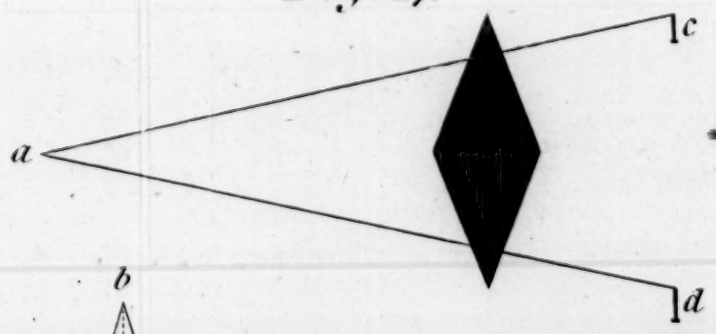


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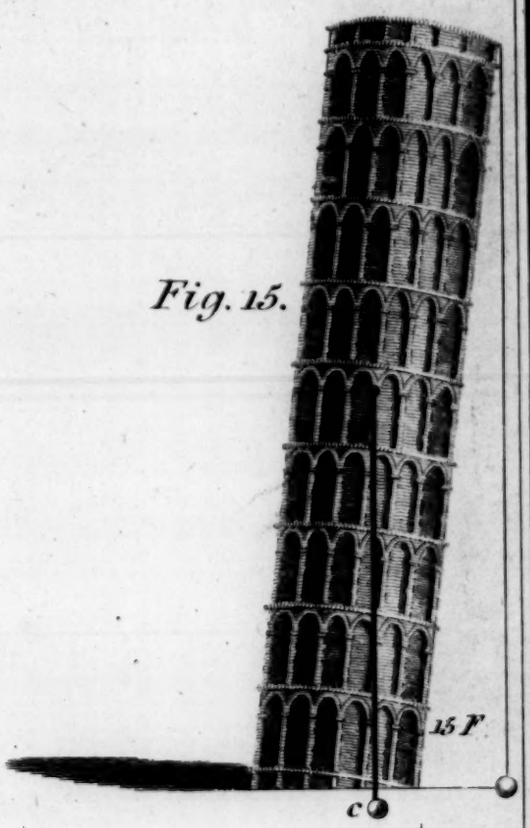
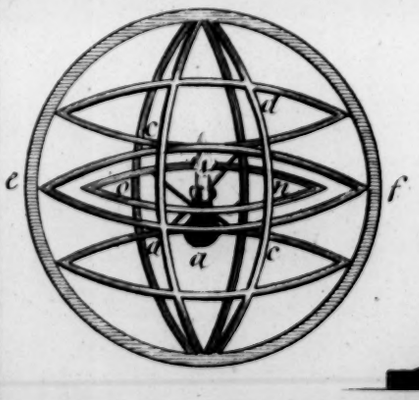


Fig. 20.



Fig. 18.



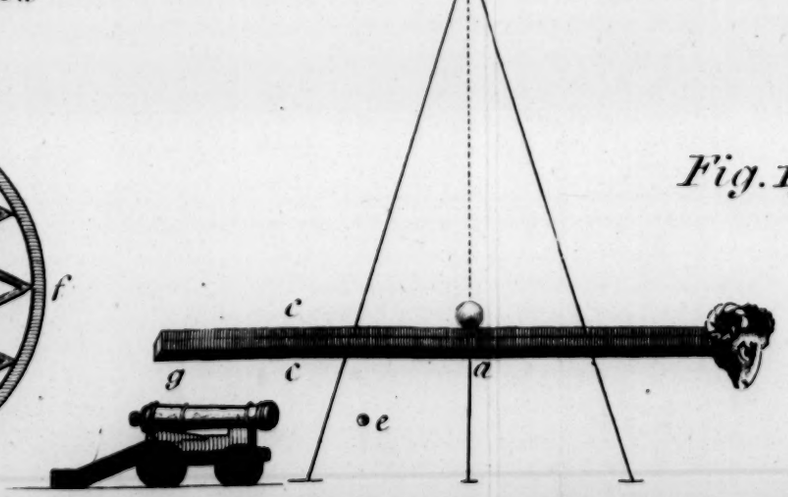


Fig. 19.



Barlow sculp.

Fig. 22.

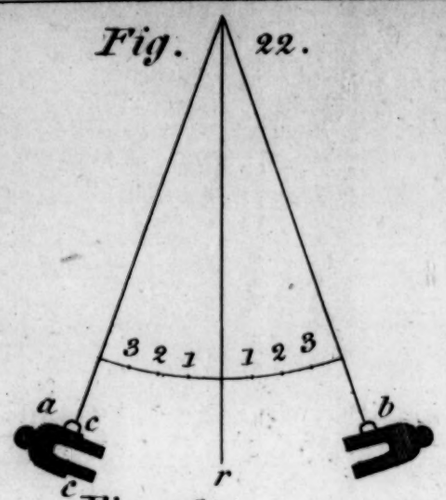


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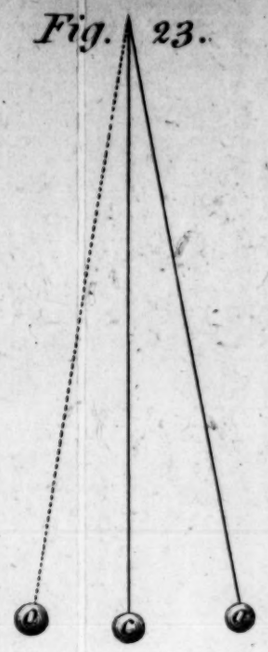


Fig. 24.

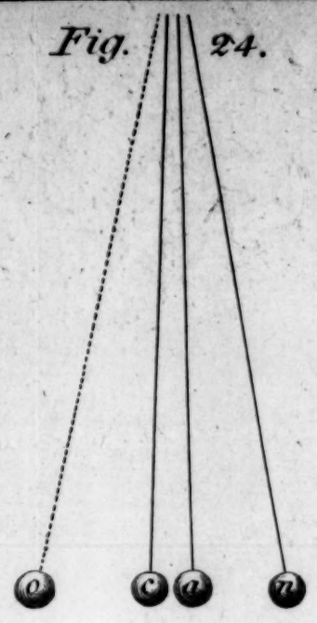


Fig. 26.

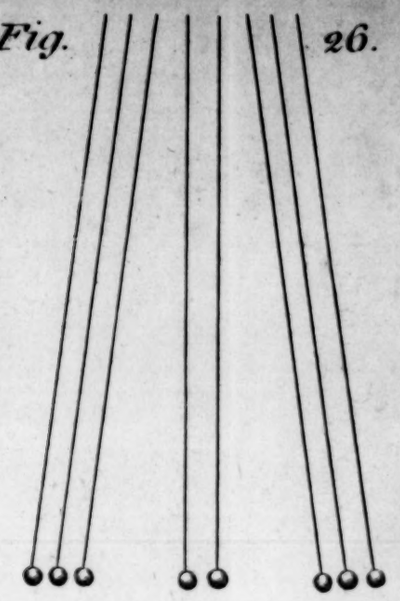


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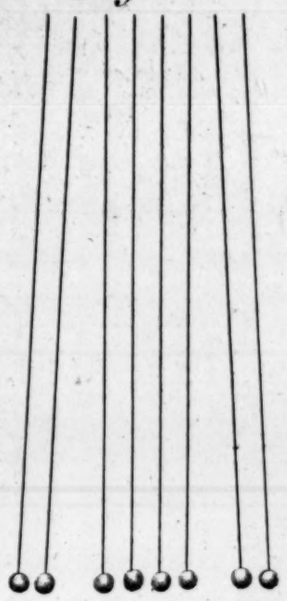
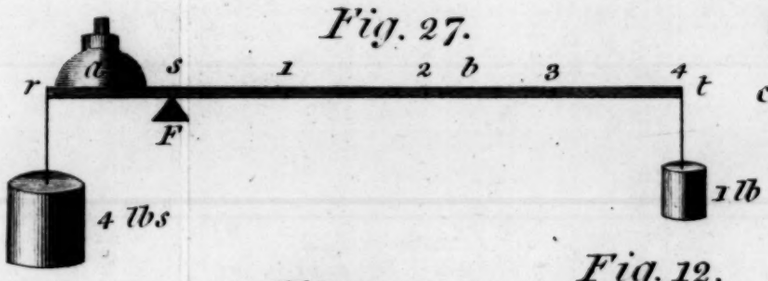


Fig. 27.



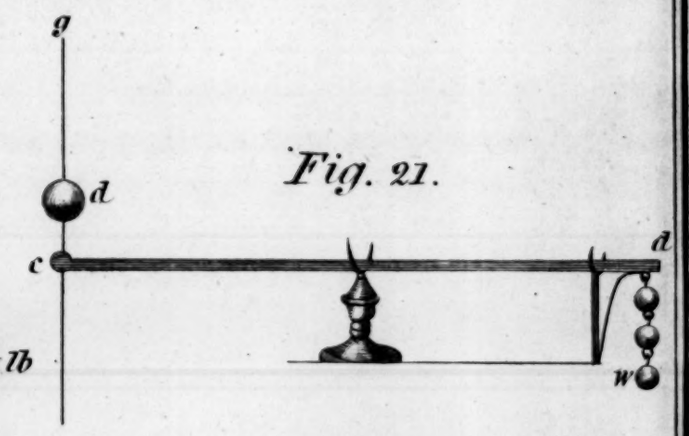


Fig. 21.

Fig. 12.

Fig. 11.



Fig. 13.

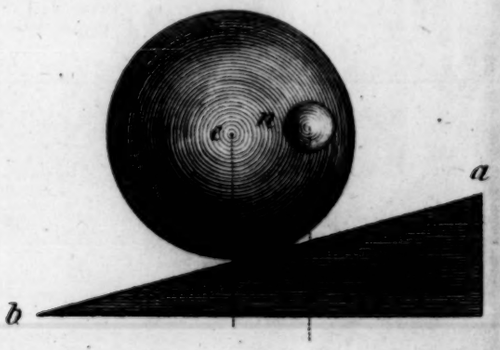
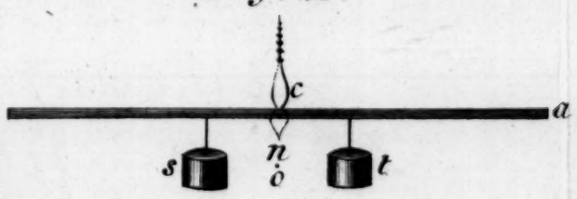


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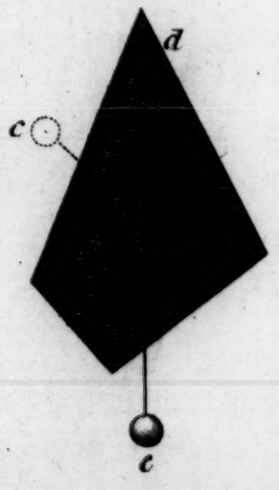


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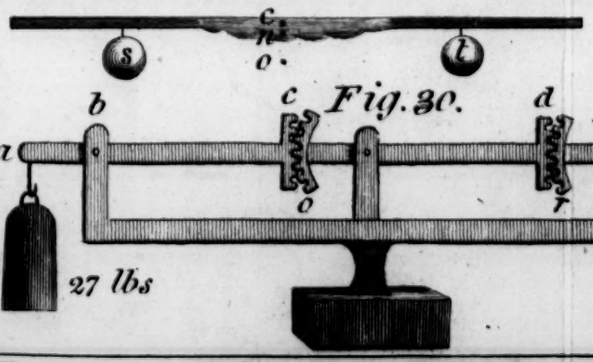


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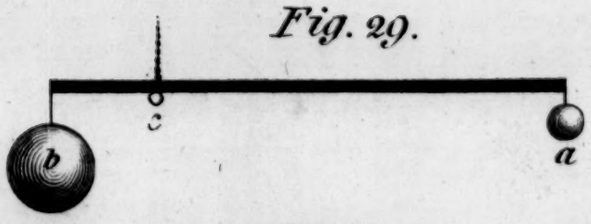
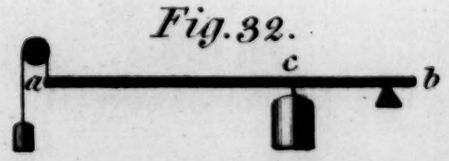
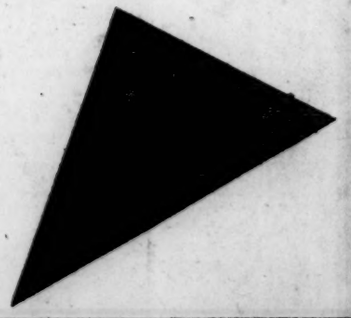


Fig. 30.

Fig. 32.





Barlow sculp.

Fig. 31.



Fig. 34.



Fig. 33.



Fig. 35.

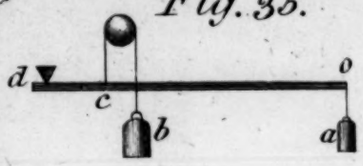


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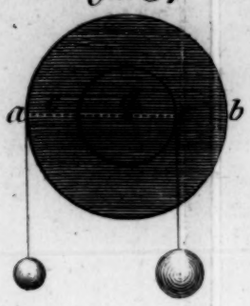


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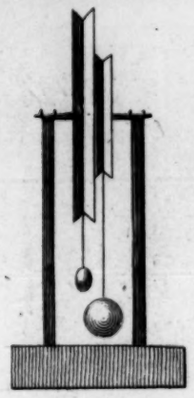


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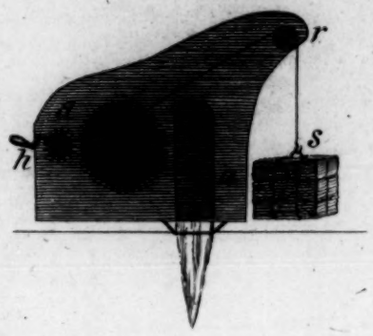


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Fig. 40.



Fig. 36.

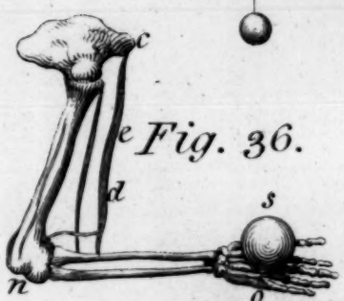


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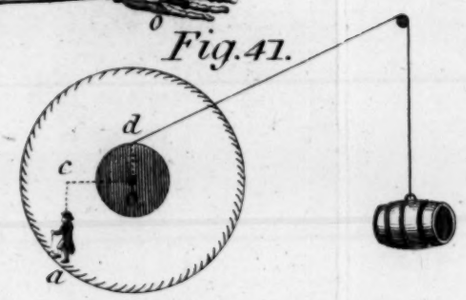


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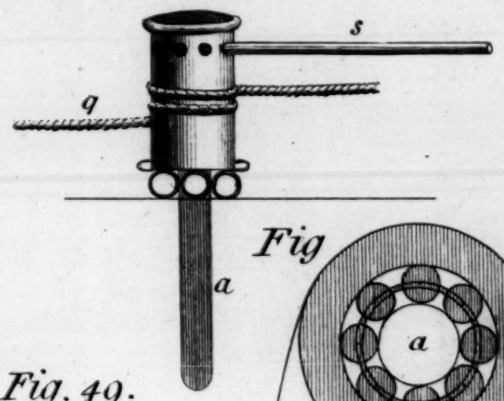


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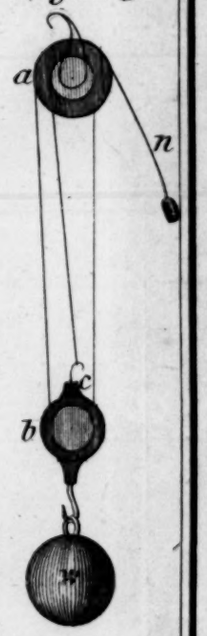


Fig. 45.



Fig. 44.

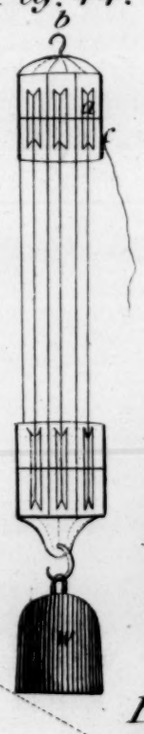


Fig. 46.



Fig. 48.

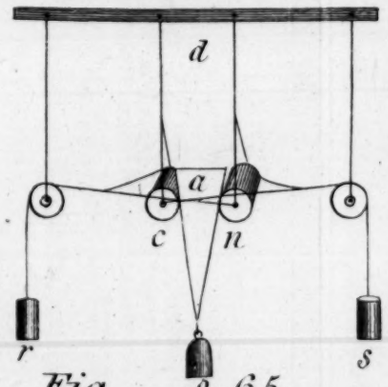


Fig 64

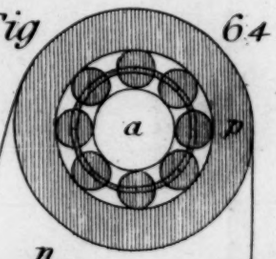


Fig. 49.

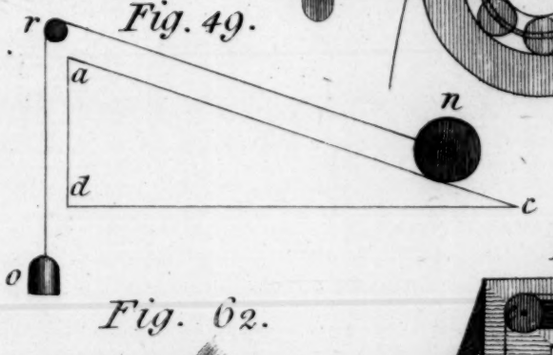


Fig. 66.

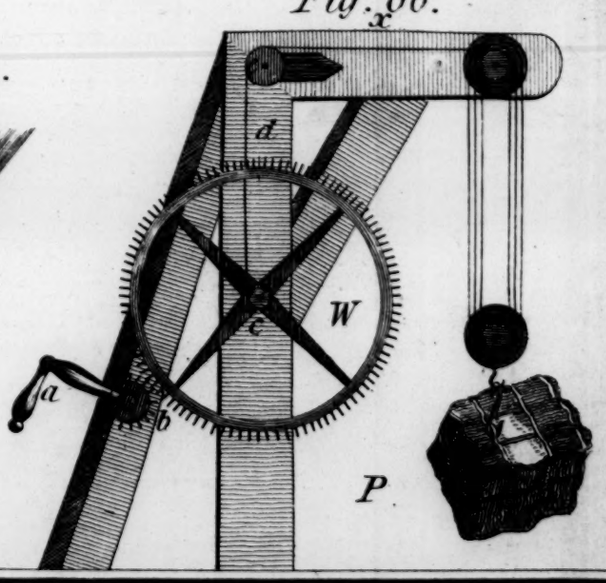


Fig. 51.

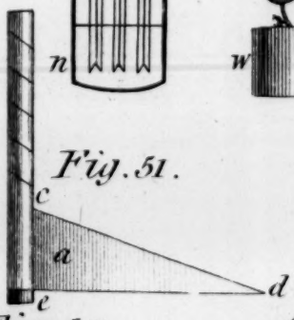


Fig. 50.

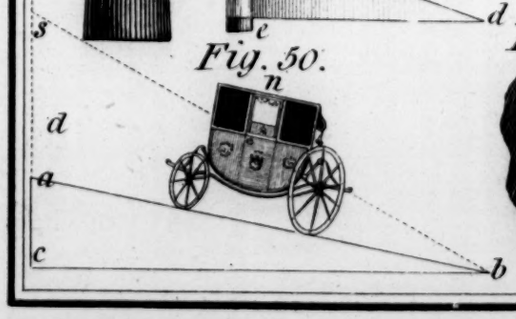


Fig. 65.

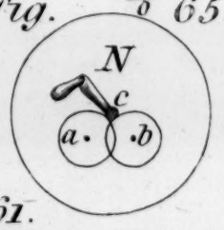


Fig. 61.



Fig. 62.

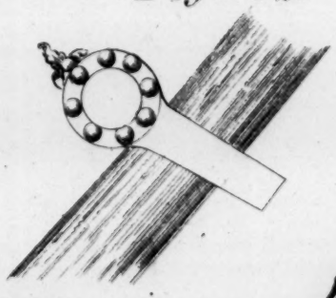
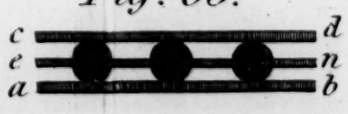


Fig. 63.



Baylon sculp

Fig. 4.

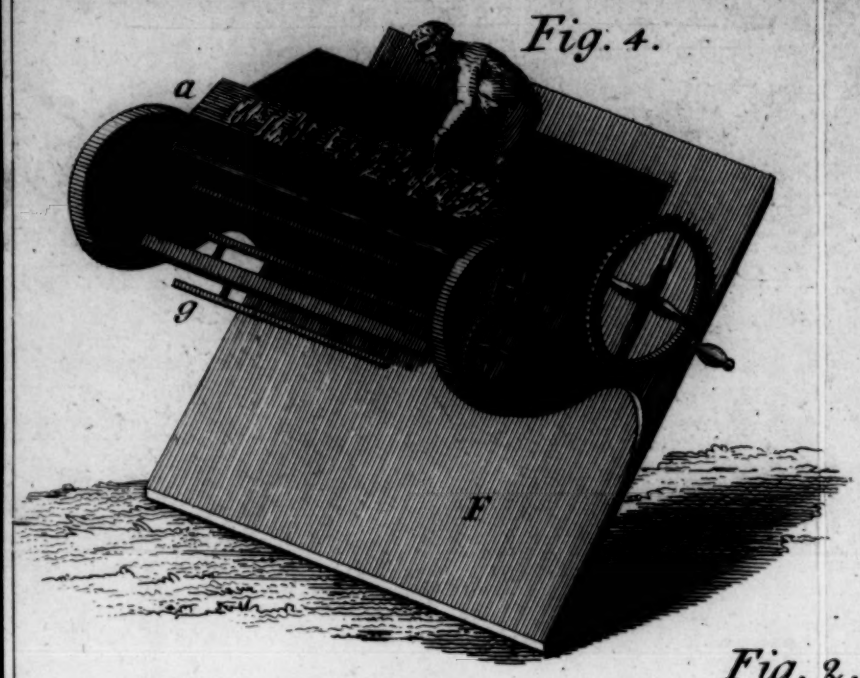


Fig. 1.

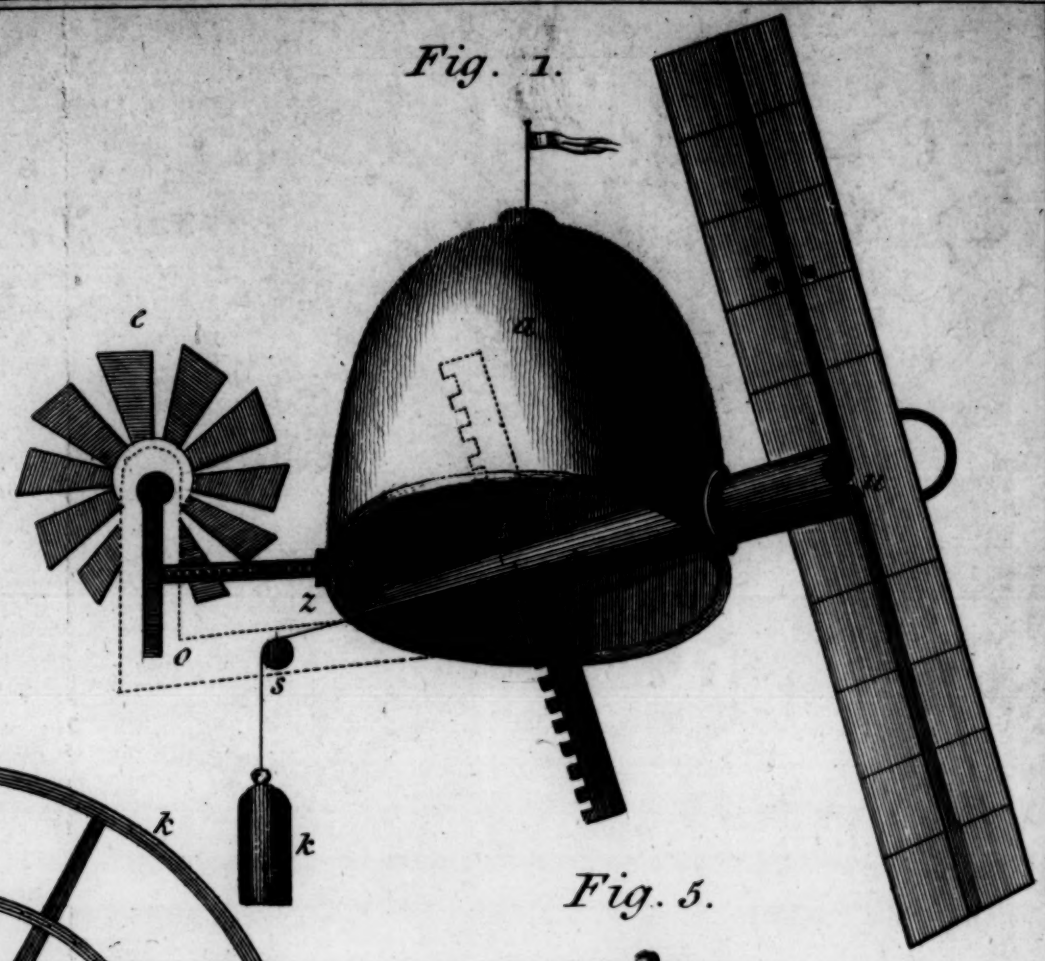


Fig. 2.

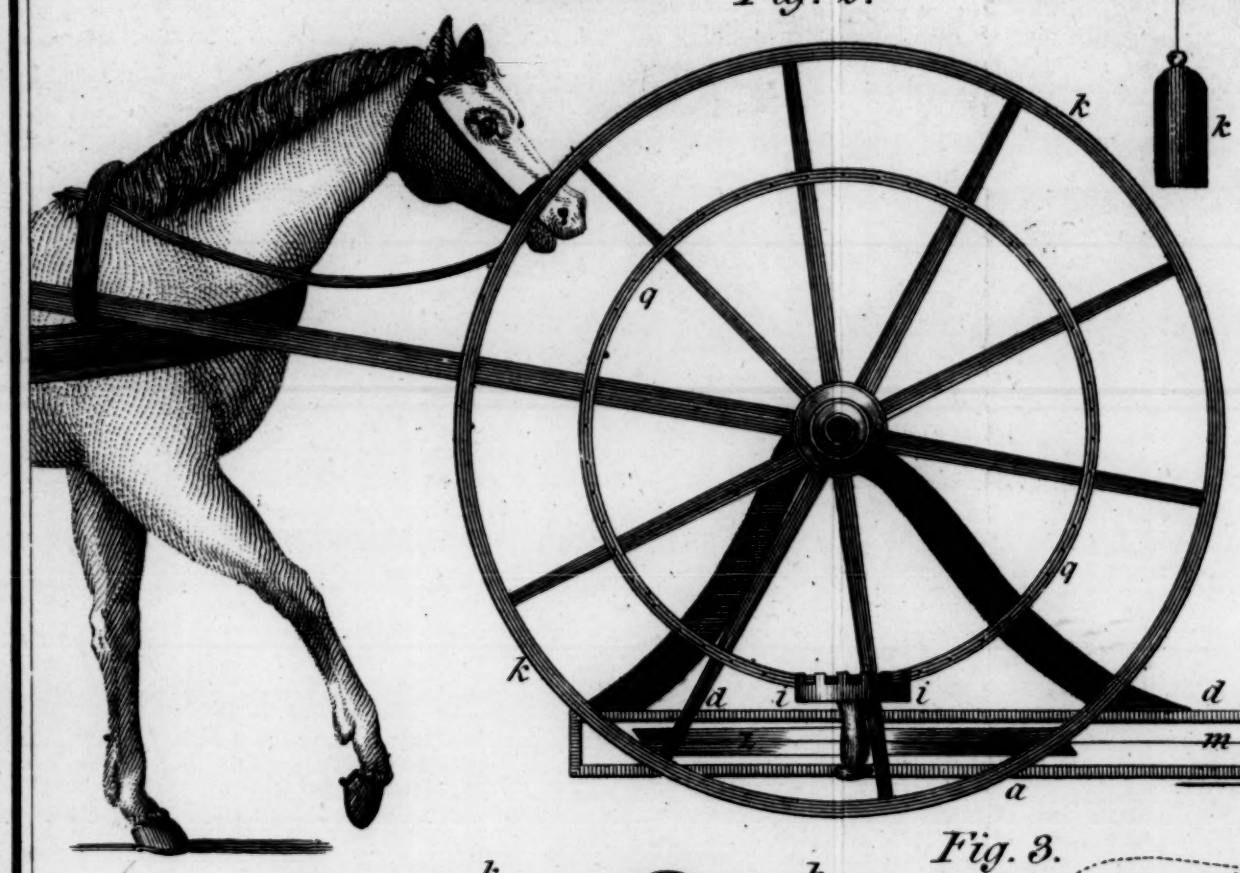


Fig. 5.

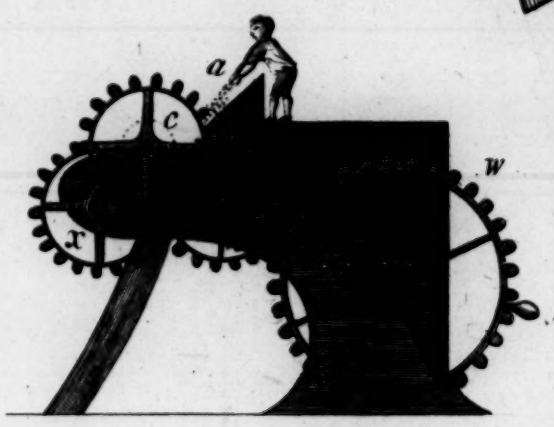
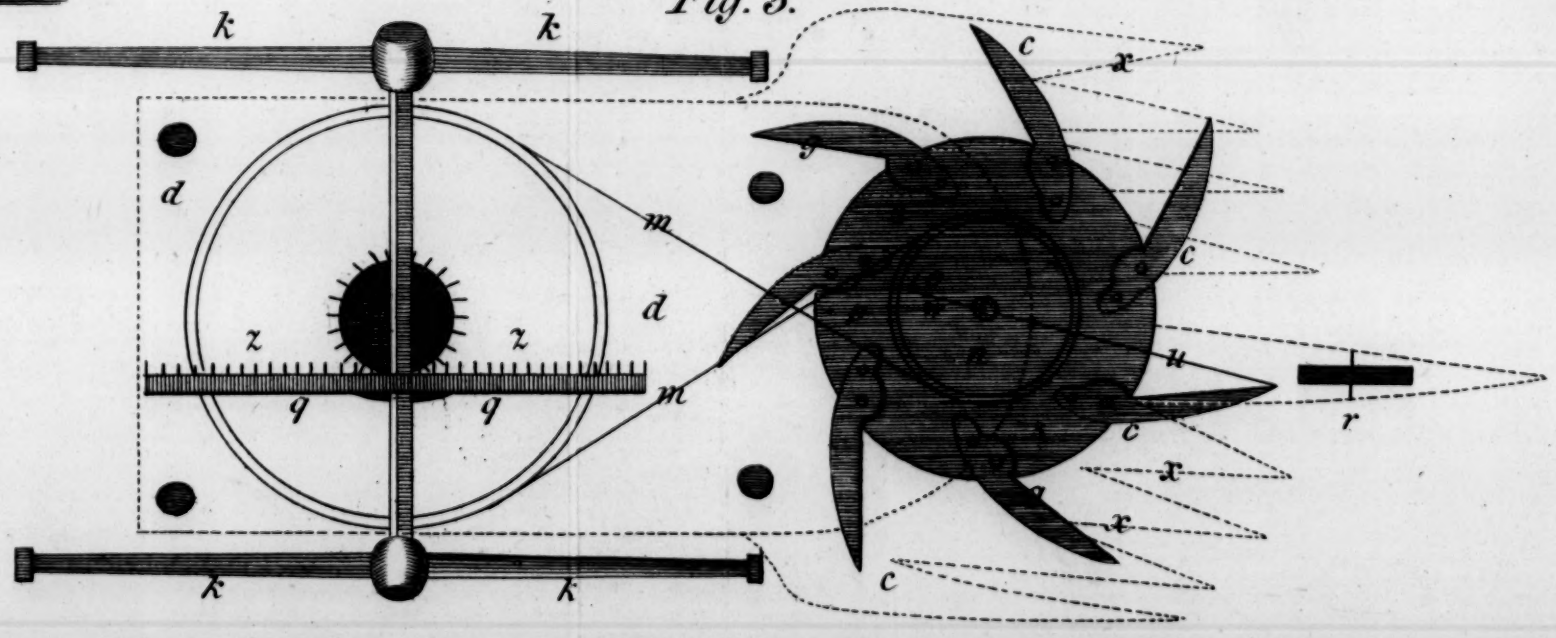


Fig. 3.



Barlow sculp.t

SECTION VI.

On the Wind-mill.

THIS machine is capable of being turned so as to face any wind, by having its top or dome sustained on such friction-rollers as are described, page 79. The ease, therefore, with which the sails, the axle, and cog-wheel, contained in the dome *a*, Fig. 1, can be turned to the wind, depends on these, and the multiplying powers of the fly-wheel *e*. This wheel consists of a number of triangular thin boards, each forming an angle of 45° with the plane of the wheel. On the axle of this wheel is a thread, or screw, which fits into the teeth of the wheel *o*, and gives motion to it; this wheel turns on an axle, whose pivot is in the support, denoted by the spotted lines, and its other end is in a socket fastened in the dome: on this axle is the pinion *z*, which turns in a fixed contrate wheel, on the wall plate of the mill. When the wind changes from the principal sails, it instantly puts the fly-wheel *e* into motion; this turns the wheel *o*, whose pinion *z*, not being able to turn the fixt wheel on the wall, is turned itself, and with it, the sails, the dome, and all that it contains: this effect continues till the fly-wheel gets into the lee of the dome; it then ceases, and the sails being brought to face the wind, are put into motion. Hence such a mill always turns itself to the wind, preventing the care of servants. The great sails produce an equal motion in an high or low wind, by being clothed with half inch boards instead of canvas; these little doors are pushed open by a strong gale,

and they shut when the wind is weak; so that by playing with the momentary inequalities of the wind, a quantity of surface is always presented in proportion to the impulses of it. A pin is stuck into the corner of each door, as at *w*, and all the pins are united to a cord, which passing over the pullies *u*, is fastened to a wire *x* going through the axle *m*; on the other end of this wire is a nut, turning in the resisting part of the crooked lever *s*, so that the motion of the sails does not interrupt the operation of the weight *k*, which can be made more or less, according to the speed the mill should go. That the wind may have its full effect upon the sails, one sail should not succeed into the place of another, before the wind has resumed its regular current; for acting upon inclined planes, it is interrupted, and obliged to push by, and give an impulse to, every sail in its passage; hence it is found that five sails is a *maximum*; i. e. they are better than four, and better than six. Wind has the greatest effect upon inclined planes, that form an angle of 45° with its direction; but as this inclination offers so great a surface of resistance to the rotatory motion of the sails, it is found that 30° near the axle degenerating gradually to 5° towards the end of the sails, is best. A mill of this construction, with each arm or sail seven feet long, is equal to the strength of a man.

Horizontal windmills are weak in comparison of those whose arms are inclined planes; for, by giving way, or falling back from the impulse of the wind, like a ship, the power is not half what it is against a plane that stands firm against the wind. But the advantage of going round always the same way, with every wind, without attendance, may, in some cases, be thought adequate to the want of power, the vast expence of building, and the unsightly tower it exhibits when built.

The reaping machine is actuated by a horse, and may be useful when corn is full ripe, and hands cannot be procured to reap it. Fig. 3 is a ground-plan of the machine; and Fig. 2 its elevation. The bottom plate, *a*, is of strong sheet-iron, to which is welded or rivetted the steel points *c c c*, each of which is a sharp edge on the sides *x x*. The wheel *s s* is of iron, and has seven knives fixed upon it, their cutting edges at *g g*. This wheel, with its knives, is put in circular motion by the pulley *n* fixed on its axle, between the two plates *a* and *d* (see the elevation). This pulley has motion given to it by the cord *m m*, which goes round the wheel *z z*; and the wheel *z* has a pinion *i i* on its axle, whose teeth conform to the cogs of the perpendicular wheel *q q*. The wheel *q q* is on the axle of the two cart-wheels *k k*, and these are put into motion by the horse, which pushes the machine forward, at his breast, as in mills that are actuated by horses. The steel points *c c* are pushed into the corn, and serve not only to hold it fast while cutting, but their sharp edges *x x* become half a pair of shears or scissars, and the circulating knives the other, by which the corn is cut, and falling on the platform *s*, is swept by the rod *u* (fixt on the axle of the wheel *n*) off the platform, and laid out of the way of the cart-wheel, so as to be easily bound up into sheaves. But when the machine returns, the lever *u* would throw the cut corn among the standing corn; it must, therefore, be taken out of its socket, and the rod *w* put in its place, the point of which, *o*, ſtands perpendicularly, and catches every revolution a lever or rod turning on the fulcrum *p*, and sweeps off the cut corn, laying it like a swath on the side already cut. This lever ought to have a spring to bring it back, when disengaged from the pin *o*, and a joint or hinge to prevent its sweeping the cut corn the wrong way. The single wheel *r* is to support the fore-part of the machine, and may be fixed higher or lower,

so as to make the stubble short or long. A semi-collar is made to fit the horse's breast, and so fixt, that he may be easily disengaged: a boy may turn the machine.

The drawings of this machine are on a scale of an inch to a foot. A horse will cut a swath two feet wide, as fast as he can walk; or rather more than could be reaped in the same time, and in the usual way, by six men.

The thrashing machine, Fig. 4, is made to strike the corn and straw both before and behind, and more effectually to beat out the grain than when struck in the usual manner, all one way. A man, Fig. 4, spreads out the sheaf on the smooth inclined plane *a*, against which the rough roller *c* draws in the sheaf, and holds it so fast while it draws it through, that the swinging flails (striking it in a contrary direction), may beat out all the corn in its passage. The flails *g* hang by hinges on the axles of the two wheels *x* and *n*, Fig. 5, which are put into motion by the first mover, the large wheel *w*. The grain and straw fall on the grating *F*, the grain falling through, while the straw is tossed off. This machine may be worked by wind or water, man or beast.

SECTION VII.

The travelling Corn-mill. Fig. 6.

THIS mill depends on the draught of a horse and the friction of the road for its motion. It is meant to move round a green, or any smooth road, and to travel from one house or village to another. *a b* is a square frame of scantling, fixed on the shafts of a common cart: in this frame is fixed the case *c*, which contains the mill-stones *d*; the upper stone as usual turned and supported by the trundle or pinion *e* (the support of which, and its regulator, cannot be represented in the drawing, but are the same as in a common mill). A cog-wheel, *A*, is fixed on a square part of the axle of the cart-wheels, and is about a foot less in diameter. This cog-wheel can be easily separated from the trundle *e*, when the mill travels from one place to another. Inclining under the stones is the bolting sieve *z z*, represented by spotted lines, with teeth that act in the trundle *e*. The flour is ejected from the stones into this circulating sieve, and falls through it into a close case that deposits it in the bag *o*; while the bran flowing through the length of the sieve, is received in another bag. The stones should be about three feet in diameter, and the whole machine covered. One horse will draw the mill and a miller, and grind a bushel of wheat in travelling about one mile and an half.

EXPERIMENTS

TO ASCERTAIN THE EXCELLENCIES AND DEFECTS OF

WHEEL CARRIAGES:

From whence Deductions are made for the Improvement of Coaches, Carts, Waggons, &c.

SECTION VIII.

IN a country where mechanics have made such a progress, where almost every operation for either use, convenience, or pleasure, seems nearly to have reached its ultimatum, it is wonderful that so little improvement has taken place in the mechanical part of our wheel carriages: in the ornamental part, I grant, art and ingenuity have gone so far towards perfection, that all nations do homage to this, by having their more elegant carriages made here. Had there been the same attention paid to their mechanical construction, and to the ease of the much-abused animals that draw them, the following experiments had not been made. I shall, therefore, take upon me to plead the cause of that first of quadrupeds, a horse; and if I am happy enough to excite any efforts in favour of his ease or comfort, I shall esteem it more than a reward for what I have done with an intention to serve him.

Before we enter upon the difficulties which wheel carriages have to surmount, it will be necessary to examine the formation of the animal by which these machines are put in motion. A horse, considered as a machine, is admirably constructed for motion, draught, or sustaining weight. His limbs, considered as an assemblage of levers, would require a volume to point out the wonders in their contrivance, and that of the muscles by which they are actuated: but the formation of his shoulders, is the subject to which I wish to direct the reader's attention.

It is evident, that at the place where the neck rises from the chest of the horse, the shoulder-blades form the resting place of his collar, or harness, into a *slope* or *inclination*; and as this slope or inclination forms an angle, with a perpendicular to the horizon of about 14 or 15 degrees, it is evident, the line of his draught should form the same angle with the horizon, because he will then pull perpendicularly to the shape of his shoulder, and all parts of that shoulder will be equally pressed by the collar. Fig. 1st. may render this more intelligible, and show that a horse draws more conformably to his mechanism in a sloping, than an horizontal line.

But the advantage he has in overcoming obstacles to his draught, by this inclined direction, is also *mechanically* great, as may be demonstrated by Fig. 2. Call *a* a wheel, *b* an obstacle, *c* the axle of the wheel, *d* the spoke which at present sustains the weight. A line drawn from the nearest part of the horizontal line of draught *c k*, to the fulcrum or obstacle at *e*, will form the acting part of a lever * *g e*; and another line *e d* being drawn from the

* What is here meant by the acting part of a lever is its longer arm, the resisting part is the shorter arm.

fulcrum *e* to the nearest part of the spoke *d*, will form the resisting part of the same lever. Now as the acting and resisting parts of the lever are of equal lengths (i. e. are signs of equal arcs), the lever becomes a scale-beam, and a draught in the line *g k* must be equal to the weight of the wheel, and all that it sustains, besides the friction. For if *g e d* be a crooked lever, a pull at *g* must be equal to all the weight supported by *d*. Now when a horse draws agreeably to the shape of his shoulder in the line *i h*, the acting part of the lever *h e* is lengthened nearly one fourth; so that if it would require a pull at *g* equal to four hundred weight, a power applied at *h* will draw the wheel over the obstacle *b* with *three hundred weight*. To those unacquainted with the principles of mechanics, this truth may be easily proved by an ordinary scale-beam. The horse himself, considered as a lever, has in this inclined draught a manifest advantage over his obstacles, in comparison of an horizontal draught, as may be seen by Fig. 3. When the horse is yoked to a post, or has any great obstacle to overcome, he converts himself into a lever, making his hind feet the fulcrum, and the centre of gravity of his body to lean over it at as great a distance as possible, by thrusting out his hind feet; by this means acting both by his weight and muscular strength, and lengthening the acting part of the lever *a b*, he overcomes the difficulty more by his *weight* than by his muscular strength: for the muscles of the fore legs act upon the bones to so great a mechanical disadvantage, that though he exerts them with all his might, they serve, in great difficulties, for little more than props to the fore-part of his body. Hence we see the great use of heavy horses for draught. But the great mechanical use and advantage of the inclined line of draught may be more particularly seen, by calling the line *a b* the acting part of a lever, and the nearest approach

from the fulcrum *b* to the inclined line of draught (that is, *b c*) the resisting part of the lever: compare this with the resisting part of a lever touching the horizontal line of draught (that is, *b d*), and it will be found nearly double; consequently, agreeable to the known properties of the lever, a weight at *g* would require double the exertion in the horse to remove it, that the same weight would require was it placed at *e*. These advantages, great as they are, are yet so obvious, that one wonders how they could be overlooked. Let any one with the model of a horse from a toy-shop, set his hind feet on the edge of a table, Fig. 4, and it will be found that he will draw double the weight along the table *a*, that he can upon the table *b*.

The obvious conclusion from the experiments is, that single-horse carts are preferable to teams:—that four horses, with each a properly constructed cart, will draw more, and with more ease to themselves, than when they are yoked in a team to one cart; because, in that case, three of the horses must draw horizontally, and consequently in a manner inconsistent with their mechanism, and the established laws of mechanics. Practice also proves the truth of this theory. The small horses of the north of England draw more weight of actual goods than our largest waggon horses, and go longer stages. The small horses of Ireland draw, as a common load, 15cwt. of goods, and travel farther per day than our waggons, and over worse roads than ours are in general: whereas 10 or 12cwt. is as much as falls to the share of one waggon horse of real goods, his superior strength being wasted upon a cumberous and ill-contrived vehicle. Waggon wheels are generally formed as Fig. 5. I suppose the reason why the wheels are made to run on an inclined axle, is to make the body of the carriage more

roomy. But what are the sacrifices that must be made to this convenience? In the first place, the machine must stand on a narrow base, and be thence very liable to be overturned; the inclined axle must be enormously strong to resist the lateral pressure of ruts and side pavements; and, worst of all, the wheels, being of a different circumference on their two sides, the smaller circumference must be reduced to the state of a sledge every time it goes round, in the proportion as it is less than the other; that is to say, if the circumference *c d* in the foregoing section be 10 inches less round than the circumference *a b*, then will 10 inches of that side of the wheel be dragged on the road like a locked wheel every time it goes round! What an additional and unnecessary draught must this be to the poor horses! and what an injury to the roads!—A broad wheel is thus rendered a mill-stone, and grinds to powder the hardest flint gravel! In vain may our legislators make laws to preserve the roads by broad wheels, so long as this absurd practice is suffered. I venture to affirm, that more real mischief is done to the roads by *such* broad wheels, than would be done by narrow ones! I have heard the late Sir George Saville say (and he was the best gentleman mechanic, both theoretical and practical, I ever knew), that he had calculated how far a waggon was rendered a sledge, in a journey to York from London. The distance is 200 miles, 30 of which the waggon is drawn as a sledge without wheels!—What a tax is this upon the horses! what a tax upon the roads! Some waggoners have found the art of making the tire of their wheels protuberant, or bulging in the middle, by which they touch a hard road with little more surface than a narrow wheel; thereby doing the same mischief as narrow wheels, and evading the tax upon them.

But of what a weight and strength must such wheels be made, to support the enormous loads laid upon them! Both of which in waggons must add exceedingly to the draught of the horses, because a waggon, from the slowness of its motion, obliges the horses to overcome its *vis inertiæ* every moment they are drawing it. That is, it is the same thing as putting it into a state of motion from a state of rest every moment: for every one knows how small a force is capable of keeping a heavy body in motion, when it is once in motion, to what is necessary to put it in motion from a state of rest. But what that difference is, will be more particularly considered hereafter. At present, I confine myself to the particular oppression of horses, and the damage done the roads, by the present mode of carrying goods from one place to another. If the aforesaid doctrine be true, viz. that a horse was designed by nature to draw in a sloping or inclined direction, then six out of the eight horses in every team must draw inconveniently, and inconsistently with their mechanism, for they *must* draw horizontally; so that much exertion is misapplied: the horse's collar is also drawn against his throat, by which his breathing is interrupted: and in cart teams (where the horses are not marshalled, as in waggons), one horse is standing still, perhaps, while another is wasting his strength in pulling him forward. One horse, to ease himself, leans one way out of the line of draught, whilst another is leaning a contrary way: in short, their strength is seldom united. I do, therefore, believe, that six horses yoked to six single carts, would draw more, with more ease to themselves, than when six are yoked in one team. But as an act of parliament says, that one man at least must accompany every team, is it not cheaper to pay for six horses, than to pay for six men? Certainly. But I venture to declare the six men unnecessary; for it is no uncommon thing to see six or eight northern single carts

driven by one man: he ties the halter of one horse to the cart which goes before it, and by this means has the whole as much at command as if they were yoked in the chains of a waggon. A horse has also the momentum of his draught increased by having a portion of the weight on his back. We may also see that there is not so great a disadvantage in the draught of low wheels as is generally imagined; for low wheels oblige the line of draught to incline, agreeably to the natural draught of the horse, which is more than an equivalent for the disadvantage a low wheel has, considered as a lever. Wheels drawn horizontally, do not increase in their mechanic power, in the proportion of their height. If a wheel be three feet six inches in height, and drawn from any part of the carriage, so that the line of draught continued might pass three inches below the centre of the axle, it would have all the advantages of a wheel of four, five, or six feet in diameter or height: for the lift in a sloping draught gives the same advantage to a small wheel, that a larger wheel would have from its mechanic power, without the incumbrance of its weight.

There is a maximum, however, in the height or diameter of wheels, beyond, or short of which, we cannot go without an outrage on mechanic propriety. In uneven countries, if wheels are above six feet in diameter, they must be made so strong, that their weight will more than counterbalance their mechanic advantage: if they are less than three feet, they are not fit for a soft country: we are here speaking of two-wheeled carriages. In four-wheeled carriages we are obliged to have low fore-wheels for the convenience of turning, not because there is any pushing quality in tall hind-wheels, according to the ideas of John the Waggoner, or of my Lord Jehu, who both place themselves and their luggage on

the fore-wheels of their respective carriages, no doubt for the wise purpose of being pushed forward by the hind ones! In my lord's phaeton the hind-wheels stalk behind, something like a tall footman following his diminutive lady, having nothing to carry but her lap-dog! Poor John has some excuse for laying the centre of gravity of his load upon the fore-wheels, because he must leave the tail of his waggon open, to receive the goods by the way, as he goes along. But that, in a phaeton, it should ever enter into the mind of man, that two riders, placed in a dangerous and ridiculously-elevated seat, with the apparatus necessary to support such a birds'-nest, together with a heavy boot, should be all loaded on those wheels the least capable of getting over obstacles, and leaving the tall hind-wheels nothing to support, is a paradox in human reasoning above my capacity to solve. Perhaps it may be matter of pride to ride on horseback without touching the horse; and, perhaps, well worth hazarding a neck to be so far elevated above our fellow-creatures. But let pride and folly enjoy their distinctions. It is the office of science to cultivate the useful.

SECTION IX.

Containing Experiments on Coaches, Chariots, Curricles, &c. &c.

TO prove that a horse should have something to lift in his draught, to give that draught its utmost momentum, the following experiments were instituted.

With a well-executed model of a four-wheeled carriage, whose

weight was 82 ounces; the forewheels $8\frac{1}{4}$ inches, as Fig. 6, and the hind-wheels $10\frac{1}{2}$ inches, drawn on an horizontal board by a line over a pulley; an obstacle $1\frac{1}{2}$ inch high was placed before the fore-wheels, and the *splinter bar* raised on the *futchels*, so as to be even with the top of the fore-wheel, as at *a*, Fig. 6. The line of draught was then horizontal as *a b*.

	Ounces.
Things being so disposed, the weight necessary to draw the fore-wheels over the obstacle was . . .	42
2d. Every thing the same as in the last experiment, only the splinter-bar lowered to *b*, so as to make the line of draught to be from three-fourths the height or diameter of the wheel. Weight required was	30
3d. All as before; only the splinter-bar so lowered to *c*, as to make the line of draught from the axle .	24
4th. Every thing as before, only the point of draught made from a splinter-bar one inch below the axle of the fore-wheel, as *d*. Weight	$22\frac{1}{2}$

Hence may be seen that the disadvantages of drawing from *above* the centre are as the sines of the respective arcs passing through the splinter bar; and the advantages of drawing from *below* the centre, also as the sines of the respective arcs. Now as the splinter-bar, or point of draught, in most of our carriages (nay, I believe, I may say all), is placed about one-fourth the

diameter of the fore-wheel above its centre, it is evident that a fortuitous pressure, equal to one-fifth of whatever weight lies upon it, is actually added to the natural weight, by this unnatural situation of the point of draught! For, by the above scheme, it may be seen that twenty-four ounces of draught surmounted the obstacle, when the pull was from the centre; and that it required thirty ounces to surmount it, at half the length of a spoke *above the centre.*

Another course of experiments, was made at my house before several gentlemen, well versed in mechanics, on a waggon-like model, weighing about 156lb.; the fore-wheels four feet two inches in diameter, and the hind-wheels five feet six inches, with an obstruction placed against the two fore-wheels of $6\frac{1}{4}$ inches.

	Pounds.
1st. The line of draught was perfectly horizontal, or even with the top of the fore-wheels; in this case, to draw it over the obstruction, required . . .	60
2d. When the direction of the line of draught made an angle with the horizon of seven degrees, by lowering the point of draught six inches below the top of the wheel, it required	48
3d. When the end of the line of draught was lowered, till the direction of it was at an angle of 11° with the horizon, it surmounted the obstruction with	41

Pounds.

4th. When the end was lowered to the centre of the wheel, and the line of draught was at an angle of 15° with the horizon, the obstacle was surmounted with 33½

5th. When the end of the line of draught was lowered to 6¼ inches below the centre or axle, so that the angle with the horizon was 17°, it was drawn over with 30½

6th. When it was lowered to one foot and half an inch below the centre of the wheel, so that the angle was 18°, it was drawn over with 29

7th. When it was lowered to 18¾ inches below the centre (being only 6¼ inches above the road, and exactly level with the height of the obstruction), the angle 23°, the weight necessary to draw it over the obstruction, was 27

These experiments, though made upon so much larger a scale than the former, produce a similar result; so that there is no reason for the too general, and often false, opinion, that what may succeed in model, or miniature, will not succeed at large.

An experiment with a common chaise, when drawn by a splinter-bar as high as the top of the fore-wheels, proved that it required 80lb. to put it in motion. When drawn from the axle, it required only 51lb.

With another chaise, and the splinter-bar three-fourths of the height of the fore-wheel, the draught over an inch obstruction, required 100lb. But when drawn from the axle, only 61lb.

With another chaise, and the splinter-bar three-fourths of the height of the fore-wheel, the draught over an inch obstacle required 119lb. But when drawn from the axle, only 93lb. So that in both cases there was one-fourth in favour of the draught from the axle.

With the same chaise, drawn up a hill rising one foot in six, with the splinter-bar one-fourth of the wheels diameter from the top, it required 168lb. to draw it up. But when drawn up the same hill from the axle, it only required 129lb.; there was, therefore, the same advantage nearly, in this mode of draught up-hill, as on level ground.

The same experiments, with larger wheels, made the advantage still greater.

Another experiment with a light coach, on level planks, was to draw it by an horizontal line from the splinter-bar; the carriage required 143lb. to put it into motion: when drawn horizontally from the axle, it required only 85lb. to put it in motion.

N.B. When ropes were fastened to the tops of the fore-wheels, the weights hung to them were but half of the above 85lb.; for, by this mode of draught, the perpendicular diameter of the wheel becomes a lever of the second kind, the ground the fulcrum, the diameter the acting part of the lever, and the semi-diameter the resisting part of the lever.

SECTION X.

Contains Experiments to ascertain the best Proportions between the Heights of the fore and hind Wheels, &c.

THE experiments were made with the model of a waggon, whose weight, with the wheels, and a load (placed in the centre of the waggon), was eighty-two ounces. The wheels, in all the experiments, being to the usual wheels, on a scale of two inches to a foot. The height of the horse's shoulder being on the same scale, four feet two inches, the medium height—the draught from the fore-axle—the obstacle half an inch high, and the angle of draught ten degrees above the horizon.

In this system of experiments, the changes were rung among wheels of every common dimension, and it is a little surprising to find so little superiority or inferiority in all the variety of combinations of heights in fore and hind wheels. Fore-wheels, however, of four feet eight inches, and hind-wheels of five feet six inches, seem to have what little advantage there is.

In putting these ideas into actual practice, it may be objected, that many inconveniences would arise to the coach-maker in altering the routine of his business, and putting his hands out of the train in which they had been used to work: if this were a general case, a bar must be put in the way of all improvement. But here no great departure is required from

the general practice. It is certainly as easy to fix the splinter-bar *under* the futchels, as *upon* them. And I see no great outrage that would be done to appearance and fashion, if the buttons on which the traces are looped, were *under* the splinter-bar, instead of being a-top. In these cases the draught would have all its mechanical advantages, and the horses would draw agreeably to their form and anatomy; the pole would have the same command of the carriage down-hill, and the same command in turning, as in the present method.

SECTION XI.

Experiments to estimate what the Draught of Carriages is on different Kinds of Roads, and on different Declivities.

BEFORE we enter upon this estimate, it will be necessary to state a theorem respecting all declivities whatsoever. A hill being but a continued obstacle, and its resistance overcome by gradation instead of abruption, or all at once, that resistance may be represented by a right-angled triangle, Fig. 7, whose base *a b* is the level of the horizon, the hypothenuse *a c* the declivity: now the sum of the draught required from *a* to *c*, would be equal to surmounting the obstacle *b c* all at once; and hence we find that the resistance which hills make to the draught, is as the length of the hill to its perpendicular height, agreeably to the doctrine of the wedge or inclined plane.

The hill *a b* rises one foot in three; for *a b* is three times *b c*. Now, agreeably to the doctrine, That the difficulty of draught is as the length of the hill to its height, it follows, that the wheel D would be put in motion on the inclined plane *a b* with one-third of the power that would lift it, and its load, perpendicularly, up any part of the line *c b*. In this case, the mechanic truth is verified, that what we gain in power, we lose in time; or that we only substitute a quantity of motion in the place of a quantity of power; for if I can roll the wheel D up the inclined plane with one-third of the exertion that would be necessary to lift it the same height perpendicularly, I must move it three times as far. The same rule holds good considering the spokes of the wheel as the acting parts of levers. The angle *e* is equal to the angle *n*, agreeably to the known truths of geometry; and the centre of gravity of the wheel *s* will have its line of direction in *s o z*; for that is the direction in which it would fall. Now a line drawn perpendicularly from *s o* to *r*, will be the sine of the arc *o r*, and be the resisting part of a lever to the spoke or radius *s r*; for where the wheel touches the inclined plane, that place may be considered as the fulcrum of the lever *s r o*. Here the same rule holds good as in the inclined plane; the acting part of the lever *s r*, is three times the length of the resisting part *o r*, and serves further to confirm the doctrine, That the resistance of hills is as their length to their perpendicular height.

WHEEL CARRIAGES.

Pl I

Fig. 1.



Fig. 3.

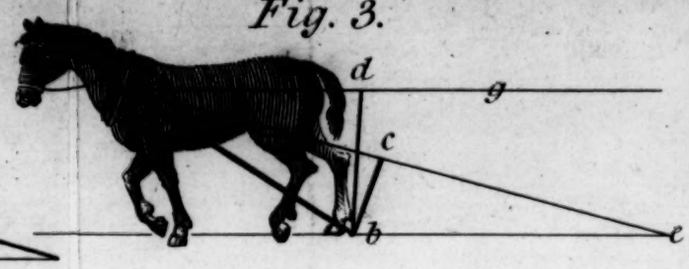


Fig. 5.

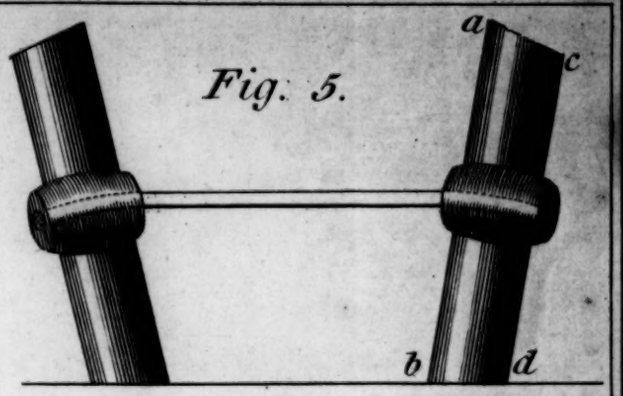


Fig. 2.

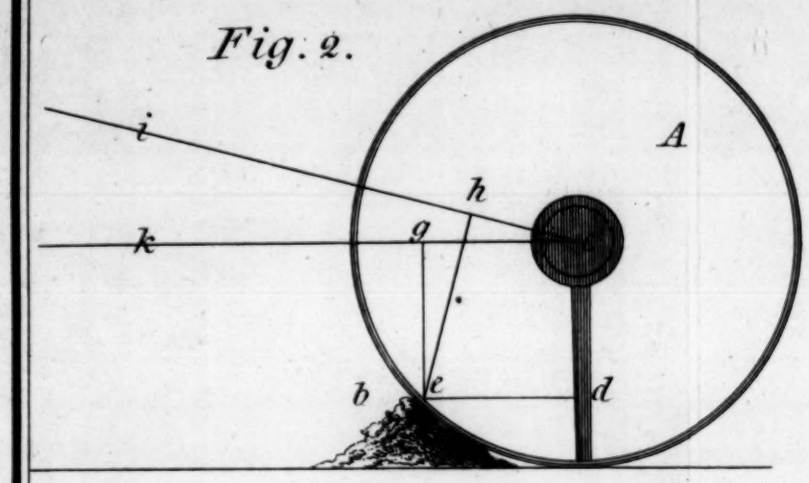


Fig. 4.

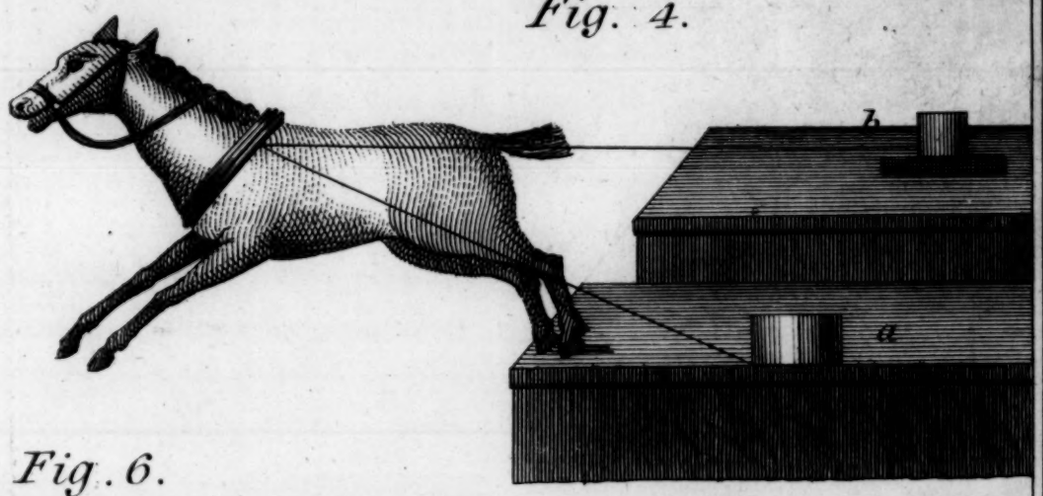


Fig. 6.

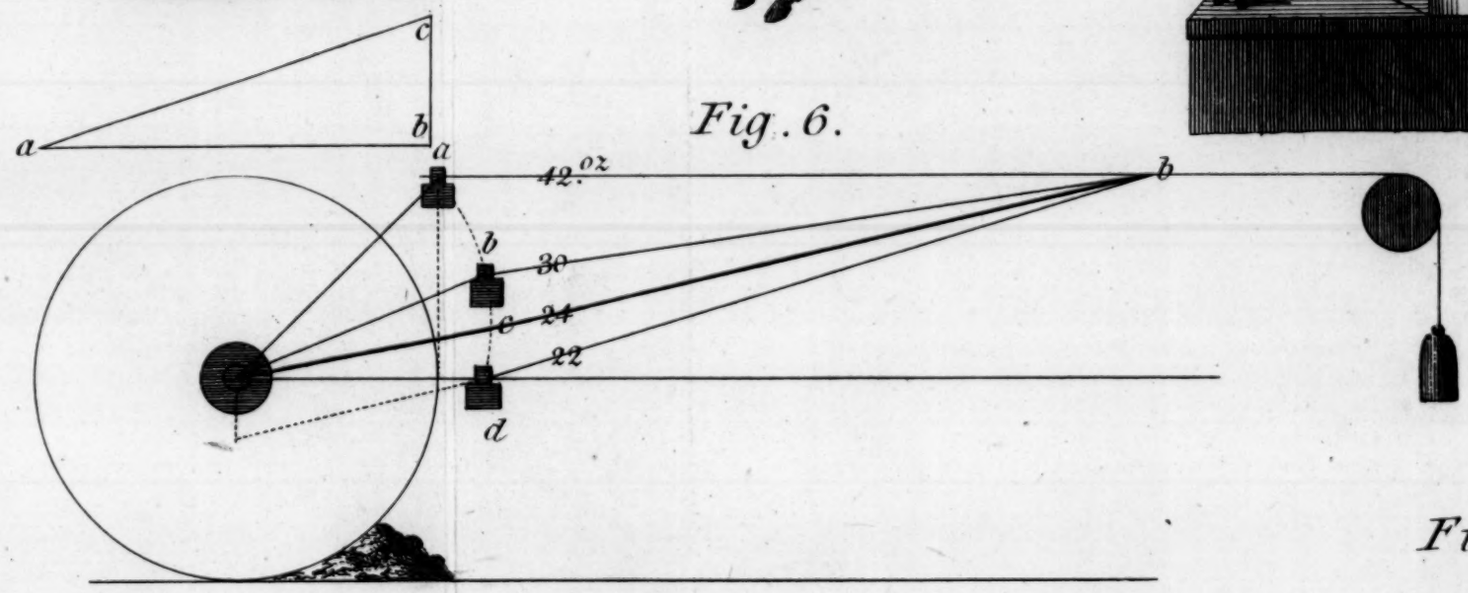


Fig. 10.



Fig. 8.

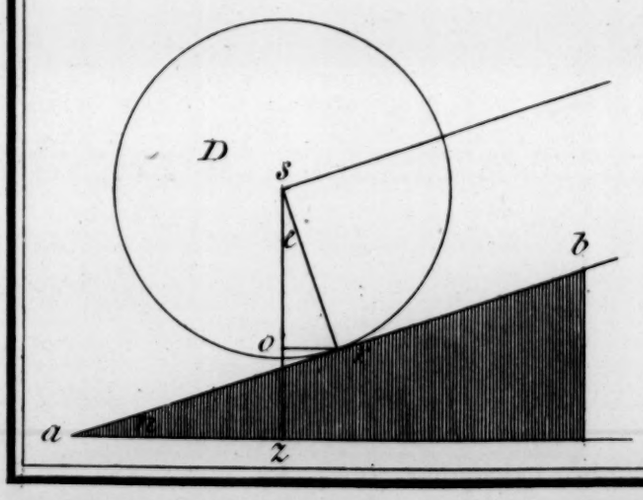


Fig. 9.

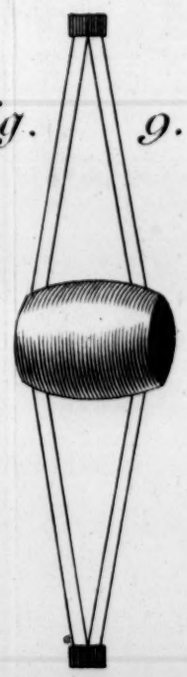
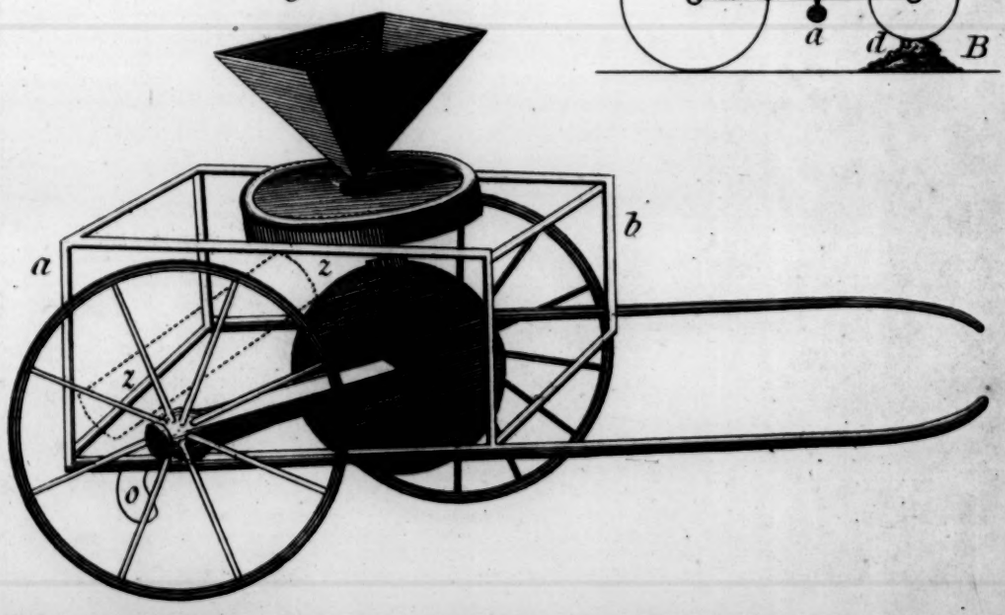


Fig. 6 N.° 2



Barlow sculp

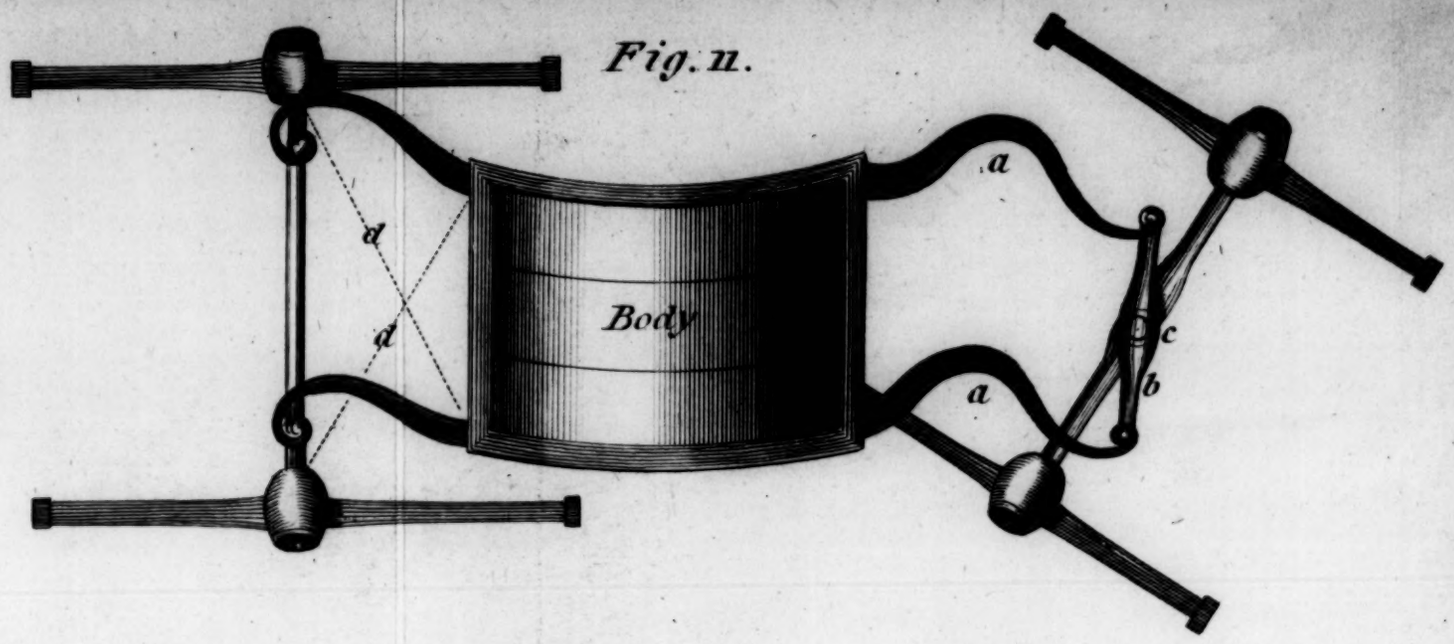


Fig. 11.

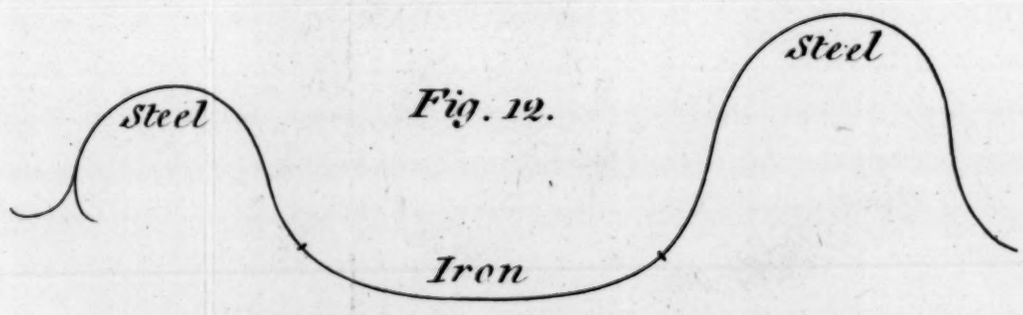


Fig. 12.

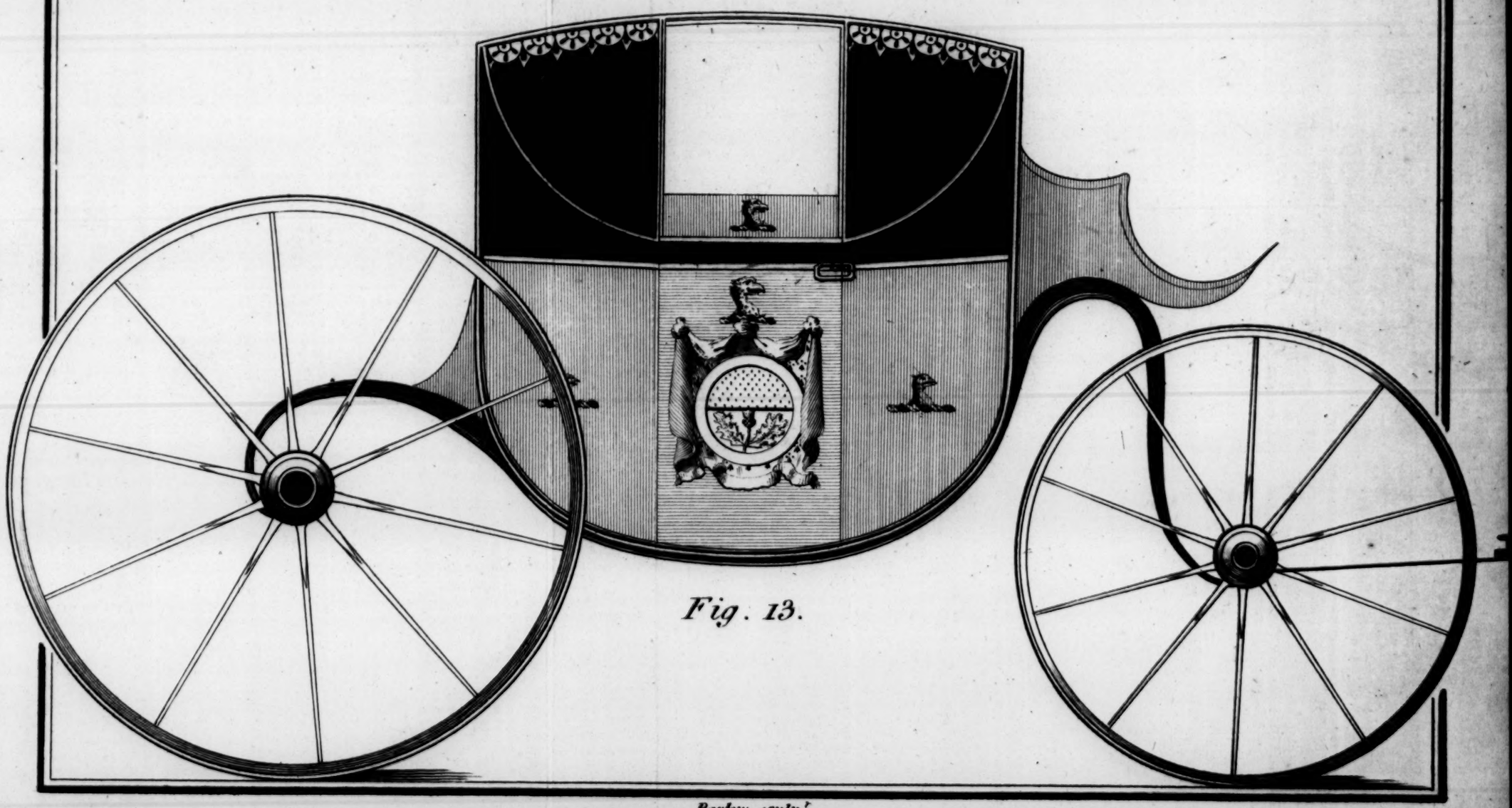


Fig. 13.

Barlow sculp.r

SECTION XII.

Miscellaneous Observations on the Excellencies and Defects of Wheel Carriages in general.

DISHED wheels, when on straight or horizontal axles, have many excellencies: they make carriages to stand on a broader base, and are less liable to overturn; they give more room to the body of the carriage, than if the spokes were perpendicular; they stand against side-jolts like an arch, and when the carriage goes on the side of the road, inclining on one side more than the other; or when the centre of gravity of the load lies over on one side, dished wheels exert a strength proportionate to the weight thrown upon them; for then the spokes on that side become perpendicular, and, of course, more capable of sustaining the additional load: but when the carriage is on level ground, and the centre of gravity equally distant from the fore and hind axle, each wheel sustains a fourth of the weight; and hence, though at that time the spokes stand inclined, they are very capable of sustaining the weight. But if the spokes were perpendicular to the nave, they would be better still; only the spokes that sustain the fellies should stand alternately on each side the perpendicular, as Fig. 9. Such a wheel is an arch both ways, and as wheels that are dished are as liable to lateral obstructions on their weak as on their strong sides, therefore a wheel armed on both sides, as the Fig. 9, is certainly stronger, has less wood, and is lighter in proportion to its strength. The mail-coaches have, in part, adopted this idea; and in

country roads it is certainly very useful; but in London, where coaches croud like the people, the naves would be perpetually clashing.

The bent fellies (when the wood is not hurt by heating) are an improvement; they are stronger, with less wood; lighter, and, of course, easier of draught.

As to friction-rollers, polished and turned boxes and axles, they are all expensive nonsense. Friction-rollers soon wear into sections, and then they are worse than the clumsiest box. And though artists would persuade us that boxes may be made so close and tight, that the axles should fill them with such nicety, that no sand, or even water, can get in, experience shews it impossible. They will please for a short time; but they will soon become like any common axle: these, and leathern boxes, are pleasant, because they lessen the usual noise of a carriage; but they are only temporary. The axles should be polished, and fit the boxes pretty close; but not so close that the attraction of cohesion should impede their motion: indeed, the friction of axles, in carriages, is, in general, so trifling, that any person conversant with mechanics stands amazed that so much attention has been paid to it. If an iron axle be made to fit its boxes pretty accurately; and, by the ordinary methods, sand and impurities be prevented from getting into them, and kept well lubricated by grease, there needs little more attention to the axles of wheels.

It has been supposed that carriages, hung very high, were drawn easier than those that hang low. If ever this idea had any influence in an informed mind, it must have been from the greater radius of

a circle, in which an high carriage acts than a low one. See Fig. 10.

If the centre of gravity of the carriage was naturally at *a*, as it ran along the plain *B*, if it met with the obstacle *d*, it would be lifted almost perpendicularly to *b*; but if the centre of gravity was as high as *c*, it would not be lifted, but thrown back, as it were, to *d*. The check given to the horses, when an high-placed carriage is thrown back, is rather worse than if the centre of gravity was lower: and it is observable that nothing checks the noble ardour of a horse so much as sudden jerks in his draught. The variety of over-turns, and the numberless necks and limbs that have been broken by means of placing the centre of gravity of the load so high above its base, have at last convinced the public, in general, of the inutility of the fashion; and, accordingly, the bodies of carriages are placed now much lower than they were some years ago. And if they were lower still, and the axles made longer, they would be still less liable to be over-turned; the carriages might be more roomy; and by having more space to play side-wise, would remove the jolts caused by the collar-braces in the present fashion. It may be said, in favour of high-placed carriages, that they keep the riders out of the dust, and give them a prospect of the country. For those who ride out only for pleasure, or an airing, I grant these are considerations; but it is not for them I write; I wish to be instrumental in easing the weary traveller, and the more weary horses that draw him.

Short carriages, also, still are considered as of easy draught: fore and hind wheels were lately brought so close, that there was scarcely room to get into the carriage. This is also in the list of errors. For if the weight be the same, the frictions and re-

sistances will be the same, whether the carriage be 10 yards or 5 in length. It is true, a few inches taken from a perch, may make it a few pounds lighter, and also a few pounds stronger; but this is not the motive, it is to make it *follow better*, according to the language of the stable.

Carriages leaning forward have also been thought to assist the horses. This position is painful to the riders, and gives no ease to the horses.

Sharp made the maximum of a carriage-wheel 2 feet diameter, Moor 8; perhaps they were both wrong. The small wheels must require an intolerable draught in soft or sandy roads; and the large wheels would tire the horses up-hill, and break their backs down-hill; for, if they are very high, they must be proportionally strong and heavy, so that though their spokes may be considered as the acting part of levers, their weight overcomes all their mechanical advantage. — Mankind, by degrees, come to what is right; $5\frac{1}{2}$ or 6 feet is certainly the maximum of a wheel, and our cart and waggon wheels have long rested at that size.

A fashion has lately started up, where stage carriages run on eight wheels. We do not find that millepedes run so fast as two and four-legged animals, nor do I think this eight-legged machine has any advantage over those of four. The friction is unnecessarily increased, both of the first and second kind. For a low wheel that turns twice round, while a larger one turns but once, must have double the *rubbing friction*, and if it be but half as high as another, it will have double the *friction by contact* on sandy, soft, or stony

roads. These impediments, multiplied by 8, become formidable. This is another added to the many oppressions under which horses labour. The roominess of the carriage admits a number of passengers, in proportion to the number of horses that draw them; and it makes no jolt at a hollow place in the road; because, when the first wheel goes over it, it does not descend into it, but goes straight over without touching; when the second wheel comes to the hollow, the carriage is supported by the 1st, 3d, and 4th, wheels, so the second passes over without touching, and thus of the rest; by this means the carriage keeps more on a level, and freer from jolts than any other carriage. This sort of carriage has begun already to be placed on four large wheels, for in its original construction it might, from its novelty, be the whim of a few months, but on that construction it cannot last long.

Single-horse carriages are as little free from mechanical errors as those of an higher class.—The springs and other accoutrements seem more calculated to enhance the price of the vehicle, than to make it last, or be easy to either the horse or riders. It would be vain to go into a detail of all the fashionable vagaries which have distinguished this machine, growing as it has, from a noddy to the present curricle. As the riders in this, like to get up in the world as well as their neighbours, a stage, as it were, must be erected on the shafts or on the axle, to set the body as high above the axle as possible, by which the riders cease to jump up and down as formerly, the trotting of the horse giving them a motion backwards and forwards horizontally, so uneasy, that many wonder why their backs should ach so severely in riding a few miles in this carriage; if they will consider the human back as

a series of hinges, playing with this absurd and unnecessary motion, the wonder will cease.

Some again believe if this kind of carriage leans forward, it will push on the wheels. To such as reason thus unmechanically, it is in vain to offer reason or common sense.

SECTION XIII.

IT may be expected, after the various faults I have taken the liberty to find with the present mechanism of wheel-carriages, I should offer some medicines for their defects and diseases. I must here, however, do justice to the workmanship and decorations of our wheel-carriages; being confessedly, in these respects, superior to all nations. For carriages of state, our country is applied to from every civilized nation on earth. The disposition of our springs, both serpentine and spiral, for shew and elegance; our carving, gilding, and varnishing; in short, in every thing where the eye is to be captivated, and where shew and state are the objects, we are unrivalled: but, unfortunately, these things seem to have absorbed or swallowed up every thing else belonging to a carriage. We seem to have lost sight of the original design of a carriage; or, rather, the eye is perverted from the main object, and the lace and ruffles become the only parts to which we attend. In what I am going to say, however, respecting what I apprehend to be an improvement in coaches, I must beg leave to be understood that ornament and decoration are out of the question. 'Tis the ease of the riders and horses I aim at; the strength and lightness of the carriage; its cheapness and durability.

In the first place, I explode the perch; I pronounce this heavy and unwieldy piece of timber, an useless load to the horses. Why should not the bottom of the body answer all its purposes?—and the fore-springs the purposes of a crane-neck?

Suppose the bottom part of the body, i. e. the timbers and spring of it, formed something in the manner of Fig. 11: *a a* fore-springs, united by the bar *b*, to which the fore-axle is attached by the bolt *c*. *d d* leathern stays, to prevent side-jolts from affecting the body of the carriage.

There are stays for the fore part, but fastened under the seat of the coachman, so as not to be expressed in the above drawing.

The shape of the bottom, and springs of the coach, may be understood from Fig. 12.

It may be asked, what advantages these carriages have over those of the present fashion?

In the first place, I estimate they may be built with every usual convenience and decoration, for two-thirds the price of coaches of the same style.

2d. They will be considerably easier of draught.

3d. They will be easier to the riders.

4th. They will be less liable to overturn.

5th. They will last longer than coaches made in the usual way, because the whole is supported upon springs; whereas the carriage-part of all coaches, at present, not being eased by the springs, strike, in a manner, so dead and unyielding against obstacles, that they are knocked in pieces long before the body of the carriage, because it is sustained by springs.

6th. It will be as easy to the coachman as to the inside passengers; which will also give much facility to the fore-wheels in surmounting obstacles. Whereas, in the present mode, an heavy coachman, and a loaden boot are perched over a small fore-wheel, and that pressed down to the ground by the futchels acting upon it as a lever (as before described). I hesitate not to pronounce that fore-wheels so loaden would require double the draught that these would, *with the same weight*.

7th. These carriages will turn in less compass, than carriages with perches.

8th. I estimate their weight at two-thirds of those of the present fashion. Of course their *vis inertiæ*, so diminished, must be friendly both to their draught and duration.

9th. A small window on each side of the coachman, will give the riders an opportunity of looking out forwards; and a lantern hung in the front of the coachman's footstool, will enlighten that part of the road where the horses are to tread. Whereas three lamps hung in the present way, are of little service to either the coachman or his cattle.

LECTURE IV.

ON CHEMISTRY.

I FEEL a diffidence in the following explanations, conscious how much I am obliged to deviate from the received, or rather the new, documents of chemistry. For being able to find little difference between the phlogiston of the old chemists, and the caloric of the new, I have made the word *fire* to answer to both.

Phlogiston was considered as fire united to some *unknown* substance. *Lavoisier* says, *caloric* is that exquisitely elastic fluid which produces *heat*. Am I excused in calling these plain *fire?* Fire, as it is generally produced on the earth, is known to be impure, and united with much terrestrial matter; and, therefore, may have given rise to the idea of an *unknown substance* being united to the simple element. I conceive fire to be united with the volatile and finer parts of terrestrial matter in the atmosphere; and that it originally issues from the sun pure, and, perhaps, in the character of electricity.

To assist those who would make a more complete scrutiny into

this most useful branch of natural philosophy, than can be in an elementary treatise, I shall first endeavour, by observations and experiments, to explain some of the general terms of chemistry.

SECTION I.

ACIDS are both in a liquid and concrete form, have a sour taste, and effervesce with alkalies.

Vitriolic or *sulphuric acid* is fluid, transparent, colourless, and without smell, like water, but twice as heavy. It is generally obtained from sulphur by distillation or burning; for the last, vital air must be present to maintain the combustion; the vessel must be close; and water must be present to imbibe the acid. There must be one part of nitre (to afford vital air) to eight parts of sulphur, in a proper vessel, inclosed within a chamber of considerable size, and lined, on all sides, with ſheet-lead (because vitriolic acid will not attack lead); there must also be a thin stratum of water covering the bottom of the chamber to attract the acid, as it rises in fumes from the burning brimstone. This combustion repeated, the water becomes oil of vitriol, as it is called, from pouring like oil, and feeling like soap between the fingers. This liquor distilled, concentrates the acid.

Nitrous acid is detached from saltpetre by the vitriolic acid seizing the alkaline bases of the nitre. The nitre is moistened with

vitriolic acid in a glass retort, with a long neck, to which, if heat be applied, the acid will rise in brown vapours, and condense into a brown liquor in a receiver. This is the smoking nitrous acid, which, if weakened by a little water, becomes aqua fortis.

Marine acid is detached from table salt by one-third its weight of vitriolic acid, as in the process for making nitrous acid. The gas comes over without heat, and should be received in water, which will greedily absorb the gas, and become marine acid, of a lemon colour, and of a smell like saffron. Salt (like nitre) contains both an acid and an alkali; but its alkali has a greater affinity to the vitriolic acid than its own; the marine acid is, therefore, dislodged from its native alkali, and unites with the water.

ALKALIS are saline substances, that combine readily with acids: in a concrete form they attract moisture from the atmosphere, and become fluid: they have an acrid burning taste; fuse with a moderate heat; dissolve earths with a strong heat; become glass, &c.

Fixt mineral alkali forms one-half of sea or table salt. It is detached from the salt by double its weight of litharge (or calcined lead), which, after they are triturated with water, and have stood for some hours, a decomposition will ensue; the acid will attach itself to the metallic calx, and the alkali remain in the water; which, on evaporation, will leave a greenish-yellow pigment.

Vegetable fixt alkali are salts found in the ashes of all vegetables, and much the same as mineral alkali. Pot-aſh is from the aſhes of wood; kelp, from fern ashes; and soda, from kali, a marine plant.

These ashes, mixt with pure water, have their salts dissolved by it, which, after filtering and evaporation, leaves the salts behind. This alkali boiled with quicklime, loses its fixt air (and the lime acquires it); it is then said to be caustic, because in striving to acquire fixt air, it corrodes and tears all animal substances with which it comes in contact. This alkali forms soap with oil, or oily matters; and with silicious earth, flint-glass.

Tartar is the essential salt of wine, which, when burnt, is also an alkaline salt, that has so strong an affinity to water, that it will attract it from the air, and become a complete solution: it has then been called oil of tartar by deliquium.

Volatile alkali. This alkaline salt is procured by decomposition from all animal, and some vegetable, substances; and by putrifaction. (See Affinity.)

SOLUTION is a property of *fluids*, whereby they imbibe, or incorporate, themselves with *solids*; separating their parts, and becoming homogeneous, or as if the particles of the solid were the same as the particles of the fluid. The sea is a solution of salt in fresh water. Ink is a solution of vitriol and galls in water. Diluted nitrous acid dissolves copper, making a solution of copper. Quicksilver dissolves lead. Gold dissolved in aqua regia is a solution of gold; and spirit of wine incorporates with camphor.

The particles of water are conceived to be round, from the fluid imbibing a quantity of foreign matter without its bulk being increased; for if salt, and then sugar, be scattered slowly into water, so as to have time to dissolve, the water will almost imbibe its own

bulk of the salts before it will appear to swell. The manner of this incorporation may be explained by making the particles of water to be represented by a glass full of marbles, and pouring in small shot amongst them to personate the salt, or any thing else incorporated with water. This may give also an idea of all mineral or other waters which derive their character from imbibing, mechanically, or chemically, the fine particles of the different strata over or through which they pass in the bowels of the earth: for the simple element is the same in all places, and only has a character from attracting and incorporating itself with the fine particles of the substances with which it has affinity, or with which it comes in contact and mixes with mechanically. Hence chalybeate springs are of water that has run over iron, or iron stone; and though it may be quite transparent, it will turn blackish with a few drops of an infusion of galls in spirits of wine. The acid of this astringent vegetable unites with iron, its ore, its calx, or salt; and the solution absorbing the light that falls on it, produces blackness, being the same as ink.

Thames water insinuates itself through its gravelly banks a considerable distance from its bed; so pumps, at some miles distance, draw up Thames water. In many parts of its progress it runs over chalk and selenitic beds (gypsum), which give it both an acid and alkaline quality in a small degree. The acid is discoverable by a few drops of a solution of tartar (oil of tartar): this alkali seizes the acid, and descends with it in a cloud to the bottom of the glass, where standing some time, it concretes into a neutral salt. The alkaline part is discoverable, in a long glass, by a few drops of a solution of the acid of sugar, when the precipitation is exhibited in long, wavy, and striated strings of singular beauty,

This acid has so strong an affinity to calcarious earths, that the smallest possible quantity in water is detected by it. This acid also attacks the teeth (as calcarious matter), and hence their blackness in those who indulge with sugar.

Many other tests discover acid and alkali in water, as syrup of violets, tincture of turnsole, &c. With the first water a polarity is formed, that qualifies the mixture to transmit red light; with the latter, green light.

Bath water is warm, and chalybeate: these properties are derived from the beds of pyrites (or fire stones) through which rain water passes in the bowels of the surrounding hills. This stone contains iron and sulphur: from the iron it derives its chalybeate quality; from both its heat. If a heap of these stones have water thrown on them, they will set fire to any combustible body in contact with them; for sulphur containing much fire and vitriolic acid, in combination with it, these qualities lie dormant till some medium forms a chemical union between them and the iron; this is water, which gives the iron a vehicle through which to draw the latent acid from the sulphur, between which there is a strong affinity. The stone, by this means, becoming slowly decomposed, the fire of the sulphur is evolved, gives out sensible heat, and the water carries that heat to the surface. A continual flame is produced by pyrites near the road between Florence and Bologna.

Spa, Pyrmont, and Seltzer water, owe their medicinal, acidulous, and sparkling qualities, to fixt air. They also contain a little iron, magnesia, and common salt: these are detected by gentle evaporation. These waters can all be imitated by art; for chalk,

marble, and all calcarious earths, hold fixt air in combination, and which can be forced out of them by stronger acids. If a little bruised chalk, in a bottle with a crane neck, have diluted vitriolic acid put to it, the air will be extricated, and may be let into the inverted jar of water, Fig. 1. This jar being shook while it receives the gas, the water in it will imbibe the air, and become acidulated like that of Pyrmont. This gas is also *forced* into common water, so as to become much stronger than the natural Spa waters.

Aix-la-Chapelle, or Harrowgate water. Sulphur, or rather hepar sulphuris, is the major ingredient in these waters; but as water will not dissolve sulphur, how come we by its solution? Hepar sulphuris, or liver of sulphur, is composed of equal weights of sulphur and pot-ash fused together in a crucible. The alkali loosens the latent fire of the sulphur, by its strong affinity to its latent acid; and hence when the hepar is exposed in air, or water, a portion of that fire is carried off, and the sulphur precipitates, as seen in the encrustations on the waters of Aix. Three parts of iron filings, and two of sulphur, melted in the same way, answer equally well, the mass being bruised and distilled as in Fig. 1, will yield a gas which the water will imbibe, and become hepatic water, smelling like rotten eggs, and curing scorbutic disorders. A few drops of nitrous acid decomposes this water, it seizes the alkali, and the sulphur falls to the bottom. It is hard to say how such a process as this is carried on in the bowels of the earth. Beds of pyrites are decomposed by water with heat;—Would not this heat and sulphur, in a bed of peatmoss (vegetable matter), produce a hepar capable of uniting with water?

DISTILLATION is the application of heat to separate fluid

and volatile parts from bodies; and to condense and collect them in other vessels by means of cold. Heat expanding all bodies, and putting their particles into a repulsive state, when this application becomes more powerful than the cohesion of the body, a separation takes place, the lighter parts rise in steam or gas, and the heavier remain. Liquors that have gone through a state of vinous fermentation, as wine, beer, &c. are disposed to part with spirit by a gentle heat, and are put in the still, *a*, Fig. 2. The fire *b*, rarifies the wine into steam, which may be represented by the little stars and circles within the still *a*; the stars as particles of repulsive fire, and the circles as the particles of the wine. These are pushed into the still-head *d*, and thence into the pipe *g*, and along the spiral pipe within *c*, till they make their exit at *z*. Hence the worm-tub, *c*, being kept always full of cold water, this condenses the steam within the worm, so that it comes out a regular fluid at *z*. Distillation may, therefore, be called a warfare between the repulsive power of heat, and the condensing power of cold; for the liquor rises in a very attenuated state in *a*; becomes more and more compact in the worm, till it ceases to be steam at *z*. Spirit rising with less heat than water, comes over first, as may be seen by holding paper dipt in it to a candle; but when the watery part of wine comes over, a paper so dipt will extinguish the candle: the tartar remains at the bottom of the still: so we find red port consists of spirit, water, and a salt.

Sea water exposed in a retort, on a fire, comes over fresh, and the salt remains in the retort, and would melt before it would rise. This is, in miniature, the mode of manufacturing table salt. Hence grapes, after fermentation, produce brandy, and spirit of wine; sugar-canes, rum; and barley, gin.

SUBLIMATION is but a distillation of dry substances. *Sulphur* in a close vessel, with a long chimney, melts with a gentle heat, and rising, adheres to the chimney, forming flowers of sulphur. *Phosphorus* just covered with water in a Florence flask, and exposed over a lamp, sublimes into the appearance of stars, and the aurora borealis. It rises with the steam of the water, and struggling to quit the water, and obtain the air, bursts into beautiful coruscations in the flask, particularly when separated from the lamp, and exposed in the dark.

Gum benzoin melted in the pot *a*, Fig. 3, on the hot iron *c*, will sublime on the sprig of rosemary in crystals like needles, surrounding every branch like a beautiful hoar frost.

Zinc, when melted in a crucible, by a hot fire, sublimes in floculæ, like pieces of cotton wool.

Saturation signifies the point at which the attractive and dissolving power of any menstruum stops, when filled with the matter it is to dissolve. Solutions of salt or sugar in water, of sulphur in oil of turpentine, camphor in spirits of wine, silver in aqua-fortis, water in air, &c. are transparent till fully saturated; if more be added, they sink in their natural form to the bottom undissolved, and the menstruum is said to be fully saturated. If water, spirits, oil, &c. be evaporated from the matters with which they are saturated, these matters assume their natural form: common salt, a cubical form; nitre, the form of a prism, &c. &c. adhering to the bottoms and sides of the containing vessels.

Crystallization signifies the various angular forms into which

salts, fluors, metals, &c. go, when they depart from a dissolved or fluid state, into that of a concrete or solid form: in which state, a part of the water in which they were dissolved is necessary to their crystallization. This is called the *water of crystallization*, which being expelled by heat, or exposure to the air, the salts lose their crystalline form, and effloresce into a mere powder.

Precipitation is performed in fluid matters only; it is a disuniting of two or more ingredients by the addition of another, which, by its greater affinity, unites with one of the ingredients, and separates the other from it, by which, they generally fall to the bottom of the liquor, and are said to be precipitated. Water issuing from copper-mines, are generally much impregnated with the calx, or ore, of copper, which wants nothing but phlogiston (or the inflammable principle), to become real copper. Ponds of such water have bars of iron placed in them, which contain much inflammable matter, and which the calx of copper will steal by means of a stronger affinity. Hence the bars become covered with copper, and much is precipitated; while the iron becomes a calx, by having lost its fire.

Calcination means the exposing a body in an open vessel, to a strong heat, till no further alteration or change can be produced in it. What remains and withstands the fire is a calx. Bodies in which fire makes no change are called refractory.

Digestion is keeping bodies over a weak fire, that combinations may be effected by time rather than heat.

Cementation. If one or more solid bodies be pulverized, and ex-

posed to a slow heat in proper vessels, the more volatile parts may be made to cement, as it were, or incorporate with the other parts.

Concentration consists in increasing the proportion of saline or other matters, by driving off the water in which they are dissolved by heat, or causing it to freeze, and then removing the ice. For alcohol may be got from common rum or brandy, by freezing the water with which these spirits are united, and the alcohol will be found in the middle of the ice.

AFFINITIVE ATTRACTION. Purposing to carry forward the mechanical and chemical philosophy hand in hand, this lecture is devoted to the first principles of the most extensive and useful branch of natural philosophy: for all arts and manufactures are little more than the composition, or decomposition, of the natural bodies of the earth. We are indebted for many of the important facts in chemical analysis to a race of visionaries, who, in the pursuit of the philosopher's stone, and the elixir vitæ, happily stumbled upon a variety of discoveries, that have been of more importance to mankind, than the grand secrets they were in pursuit of would, had they been found out. These facts, though now systemized into a tolerably regular and consistent theory, simple in its principles, and, seemingly, accordant in its various ramifications; yet, I am sorry to say, it does not *quite* agree with the experiments and observations I have been enabled to make. I think the grand basis of chemistry is attraction and repulsion. By attraction, I mean not only that of cohesion and gravitation (formerly explained), but the affinities of matter; the elective attractions, or local affections, of it, that is, the tendency

which the constituent parts of bodies have to unite readily with some substances, in preference, as it were, to all other parts of matter. Water and spirits are said to have an affinity, because they unite with the utmost readiness and affection. Water and oil have no affinity, because they will not unite (except by the intervention of an alkali, by which they become soap); for if oil and water are shaken together, it will be found the parts of each attract those of the same kind more strongly than the other. Acids and alkalis have so strong an affinity, that they rush into union with effervescence and ebullition; so strong, indeed, is the attachment between acids and alkalis, that one will detach the other from most compounds, with which that other is united. The sea is a compound of fresh water and salt; yet so perfectly clear and homogeneous (as solutions generally are) that water and salt may be said to have affinity. That this selection, this choice, as it were, is but a modification of the attraction of cohesion, I entertain no doubt; for as various effects in chemical experiments prove the particles of matter to be of various shapes or forms, such particles, as by their figure can lie conveniently by the sides of each other, or admit their centres coming nearer together, will adhere more strongly, than those combinations where the corners and edges of particles do not fit, but inclose great spaces or interstices among them. This last may be called the attraction of cohesion; the other the attraction of affinity; but it is a distinction with little difference.

1st. Spirit of wine dissolves a large quantity of camphor without losing its fluidity or transparency. The spirit is called the menstruum, or solvent; but this menstruum having a greater affinity to water than to camphor, upon the admission of water to this solu-

tion, the spirit forsakes the camphor, and uniting with the water, the camphor is said to be precipitated, though it swims on the surface of the fluid. This effect is produced by simple affinity.

2d. Silver will dissolve in diluted nitric acid (or lunea cornea), become homogeneous with it, or as clear as if it were one simple fluid: but nitrous acid has a greater affinity to copper than to silver; copper, therefore, put into this solution, precipitates the silver, which shoots into those beautiful ramifications called the Arbor Dianæ.

3d. Salt of tartar, mixt with salt of mercury (or sublimate, as it is called), will form no union when dry; but mixt with water, a singular polarity takes place; they form an orange coagulum, unlike any of the ingredients: but the tartar is an alkali, and has a stronger affinity to an acid, than to the sublimate of mercury; hence a few drops of strong nitric acid instantly dissolves this union, the colour is discharged, and the whole becomes transparent.

4th. The salt of copper (blue vitriol) dissolved in water, has no colour; but a few drops of the spirit of sal-ammoniac gives it a polarity, that qualifies it to transmit blue light: this polarity is deranged by a few drops of the nitric acid; for by its seizing the alkali, the whole again becomes colourless. But to bring about its former polarity, and qualify it again to transmit blue light, if a stronger alkali (oil of tartar) be added, the colour will return.

5th. Salts instantly precipitate and crystallize when spirit of wine is added to their solution in water; for water has a greater affinity to spirit than to salt.

6th. Unions are often formed by two bodies, where their product is totally unlike either. Diluted vitriolic (sulphuric) acid will attack iron, drive out its fire in the character of air, and, uniting with the iron, or rather its calx, form a salt unlike either the acid or the iron, called martial vitriol.

7th. Epsom salt (sulphate of magnesia) consists of magnesia, united with the marine acid. When this salt is dissolved in water, if salt of tartar (a strong alkali) be added, it will seize the acid, and detaching it from the magnesia, the magnesia will be precipitated, or fall to the bottom of the solution, in the form of white powder. Or if an equal quantity of a strong solution of Epsom salt be put to a strong solution of tartar (oil of tartar), the union will form a solid, which is the magnesia of the shops.

8th. Nitre is decomposed by the vitriolic acid (sulphuric acid), for this acid will seize the alkaline bases of the nitre, and form with it a vitriolated tartar. But the acid of the nitre, being thus forsaken, has its revenge; for if it be mixed with the vitriolated tartar, it drives out the vitriolic acid in its turn, and seizing its alkaline bases, forms with it a true nitre, such as existed before the operation. This is called reciprocal affinity.

9th. Common salt is a compound of marine acid, and marine alkali; but this alkali (as above) having a greater affinity with the vitriolic acid, will, when it is poured in, forsake its own acid, and leave it, flying off in fumes. The new salt so formed is called glaubers salt. Liver of sulphur consists of sulphur and fixt alkali: water will not unite with sulphur; but as fixt alkali has a great affinity with both sulphur and water, it serves as an intermedium to

unite these two substances together. Hence the sulphuric waters of Aix-la-Chapelle, Harrowgate, &c. These are common instances of this species of attraction. Three or four heterogeneous ingredients will, in many instances, attack one another, where affinity could only take place from the joint action of two against a third, or a fourth, ingredient; from which often results two decompositions, and two new combinations. This is called double affinity.

10th. To disengage the volatile alkali from sal-ammoniac, if a mixture of two parts of chalk, and one of sal-ammoniac in powder, be exposed to a sand heat, in a retort, adapted to a receiver, a change of principles will take place. The chalk consists of lime and fixt air; the ammoniac of volatile alkali, and marine acid. Both are decomposed; the lime unites with the marine acid, and forms a fixt salt in the retort; and fixt air unites with the volatile alkali, and passes into the receiver, where it forms a white salt, of a pungent smell. This is the sal volatile of the shops, and used for smelling-bottles.

Because the law of this, and the other species of cohesive attraction, do not seem to follow the laws of gravity (by diminishing as the squares of the distances increase), some imagine them of a distinct and different nature from the attraction that holds the earth and the planets together. But can such small masses as we can make our experiments upon, betray the same strong phænomena as a world, a planet, or a sun? Could we measure the ratio of the attraction, exhibited between two corks running to meet each other, when swimming on the surface of water, I entertain little doubt but it would be found to be in the same ratio as the laws of gravitation. Magnetic and electric attraction proba-

bly are the same also. Similar phænomena must arise from the same law, if we are not to multiply causes; which certainly is a most excellent rule in philosophizing, or examining nature.

Objections are also made to fire and light being the same, because heated iron exhibits no light till it becomes violently heated. Fire lying in a latent state in metals, must be strongly excited by external heat, before it will betray signs of activity, or sensible light: for metals have so strong an affinity to fire, and retain it with so strong an attraction, that they must be attacked with great violence by external fire, or force, before they will part with their own.

11th. If a piece of wood, and a piece of iron be put in the same fire, the wood will let out its light, in a white flame, in a few seconds; but the iron, from its strong affinity to light, lets it out by degrees; the violet (as weakest part) is seen on its surface first; the heat increased, the blue part of light appears on its surface (at this stage it is frequently taken from the fire, the colour congeals on its surface, and hence we have utensils and toys of blue steel, &c.). The heat increasing, the other colours, as green, yellow, red, will be expelled in prismatic succession: but when the heat becomes intense, the light is forced out all together, and the iron becomes white; indicative of the mixture of the seven primitive colours contained in all light.

Affinities are not confined to the grosser bodies of the chemists; they exist through all nature. Electricity, light, fire, air, water, &c. have all a tendency to unite with some bodies in preference to others. We see, then, that one substance will dislodge another,

where greater affinity takes place; and that we can make tables of the relationship which one kind of matter has to another, and thereby know the results of most kinds of mixtures beforehand. For if a fixt alkaline salt be united with a vegetable acid, as vinegar, and formed into a neutral salt; on adding to this compound some marine acid, the acetous acid (vinegar) will be disengaged, so as to fly off in a moderate heat, leaving the marine acid in possession of the alkali: if then the nitrous acid be added, it will, in like manner, dispossess the marine, which will rise in white fumes; though, without such an addition, it could not be detached from the alkali by any degree of heat: but on the addition of the vitriolic acid, the nitrous gives way in its turn, exhaling in red fumes, leaving the last acid in full possession of the original alkali.

From numberless affinities like these, that have been discovered by the labours and experiments of the laboratory, have resulted the useful tables of affinities by Geofroy, Bergman, Black, &c. A specimen of which can only be given in this work. The substance, to which other substances are related, is generally placed in capitals at the top of the table; and the next substance under it, is that to which it has the greatest affinity; the next under that a less, and so on, thus:

VITRIOLIC ACID.	NITROUS ACID.	LIME.	FOSSIL ALKALI.
Terra ponderosa	Vegetable alkali	Acid of sugar	Vitriolic acid
Vegetable alkali	Fossil alkali	Acid of sorrel	Nitrous acid
Fossil alkali	Terra ponderosa	Vitriolic acid	Marine acid
Lime	Lime	Acid of tartar	Phosphoric acid
Magnesia	Magnesia	Phosphoric acid	Acid of sugar
Volatile alkali	Volatile alkali	Nitrous acid	Acid of tartar
Clay	Clay	Marine acid	Acid of sorrel
Zinc	Zinc	Acid of lemons	Acid of lemons
Iron	Iron	Acid of benzoin	Acid of benzoin
Lead	Lead	Acetous acid	Acetous acid
Tin	Tin	Acid of borax	Acid of borax
Copper	Copper	Aërial acid	Aërial acid
Antimony	Antimony	Water, &c.	Water
Arsenic	Arsenic		Unctuous oils, &c.
Mercury	Mercury		
Silver, Gold, &c.			

SECTION II.

Of Combustion.

WHEN heat is applied to wood, the inflammable principle of the wood (i. e. the light it had derived from the sun) has that dormant principle of expansion put into action by the heat; and if vital air be about it, combustion and decomposition will take place; the wood (like every thing else) turning black, before it parts with its light to the surrounding space. A smoke is produced, which is a mixture of water, oil, volatile salts, air, &c. And when the heat is carried to a certain point, the wood takes fire, and the combustion proceeds till the inflammable principle is dissipated. In this operation, there is a diminution of the air about it; and light, and its concomitant heat, are extricated. For as no inflammation will take place without air, air must mix itself with the heated vapour, before it will ignite into real flame. As resins are a product of the sun, the more there are in any vegetable, the greater will be the light and heat in the combustion. The soot produced in this process, consists of parts imperfectly burnt, that are decomposed only in part, and have escaped the action of air, and which may, therefore, be burnt over again. For when the combustion is perfect or effectual, as in Argand's lamp, there is no perceptible smoke. The fixed matter after combustion is ashes, containing salts, earth, and often iron and other metals. Is not this process, first disturbing and then igniting the fixed light of the combustible body, by the near approach and contact of another body, already in a state of heat and combustion? Must not coals, candles, wood, &c. be heated before they will ignite, by

which the light of the body to be burnt had its dormant repulsion excited? The body swells, admits the neighbouring ignition, and has its latent light let loose or expelled in the character of flame; and is not this the light it originally derived from the sun? Air being kept in a state of fluidity, by the latent fire or light united with it, is necessary to the support of flame. How? It adds fire to fire. For the fire contained in the air around the ignited body joins the combustion, and is also dispersed; the air first swells, by its inherent fire being excited by heat, and then becomes diminished in its volume, by losing a considerable portion of that fire, and of course of that repulsion, which set the particles of the surrounding air at a distance. Why then should we believe, with modern chemists, that the pure part of the air is absorbed by the body in combustion? We find no air in the snuff of a candle, nor in the ashes of coals or wood.

This doctrine is not meant to invalidate the well-known facts, that metals, while calcining, require a current of air to pass over them; that they imbibe a portion of the pure air in that passage, and diminish air confined with them in close vessels, when calcining by the use of burning glasses. These, and many other circumstances, prove that air is imbibed by metals when in a state of fusion; and that they would not calcine to a calx, or oxyd, without pure air; and that it is that air, going into a concrete state in the calx, that makes the oxyd of a metal, so calcined, heavier than the metal from whence it was made: for a pig of lead, 100lb. weight, will produce 110lb. of minium.

Though it is an article in our chemical faith, that nothing is

destroyed; that the original particles of matter are the same as they came out of the hands of their great Maker; and that it is their various combinations that cause that variety we see in bodies—I fear this is not strictly true. Air certainly is diminished, or lost, or annihilated, where combustion is going on; and it is not to be found in the ashes or cinders of burnt bodies. Yet these ashes and cinders become again combustible by exposure to light; for, so exposed, they rise again in vegetables, and all vegetables are combustible: thus may be verified the assertion, that "light unburns burnt bodies."

Marble, chalk, shells, and all calcarious earths, may be supposed to have no affinity to fire or light; for they let out none in their decomposition. When burnt in the fire, they may be made red hot, but they produce no flame: the fixt air, one of their constituent parts, extinguishes flame, and resists the entrance of electricity. For fire propagates itself with most difficulty through such bodies as refuse to conduct electricity; and *vice versa.* When calcarious earths are calcined, or burnt into lime, their fixt air, and water, are expelled, and fire is forced into their place. Hence a quantity of fixt fire becomes a quality of the quick lime, which sleeps latent and insensible, till called into action by the stronger affinity of water: this applied, the calcarious basis seizes its old friend, and expels the new, which flies off in sensible heat. Fixt air being also applied, the mass will become marble, chalk, shells, &c. again.

Thus we see that nature has two ways of cooling bodies, the one by dissipating fire, the other by fixing it. For different bodies at the same temperature really possess very different quantities of

fire, though they raise the thermometer to the same degree; for some bodies have a stronger affinity to fire, and absorb it in greater abundance, than others.

When we burn a combustible body to obtain heat, we obtain the greatest part of the fire from the air with which it was combined and surrounded: and the colder that air, the more fire, because more passes through it in the same time.

As fire propagates itself through metallic bodies more easily than such as resist electricity, we find that molten lead poured into a square vessel, three sides of which are of wood, and the fourth of lead, the heat will penetrate the lead soonest, and cool on that side soonest.

That air is necessary to combustion, is exemplified in its mixture with the vapour rising from a fire, or candle, and qualifying that vapour to become flame. For heat penetrating the wick of a candle, rarefies and sends off a quantity of unconsumed oil in vapour. If a tube of paper, eight inches long, be held over the candle when blown out, and a lighted piece of paper be held over the upper end of the cylinder, the fire will follow the hot vapour down it, and light the candle.

The specific fire contained in bodies being incapable of measurement by the thermometer, a means has been invented of ascertaining it by the quantity of ice which bodies, at an equal temperature, will dissolve in the same time. The difference of the quantity dissolved is supposed to give the proportion of specific fire contained in the several bodies. This instrument is called a calorimeter.

This instrument has its ice, and the bodies to be tried, surrounded by an inclosed cavity of air, to secure the materials from the action of the outward air, or heat or cold of contiguous bodies; for air and water may be almost said to be non-conductors of heat. If the end of a red-hot iron be held perpendicularly, an inch distance, over a drop of water, on wood or metal, the water, wood, or metal, will receive no heat. Hence the lids of kitchen pans being made hollow (to contain more air), the heat cannot escape, and the contents within are heated, and kept so with a small fire.

Salts, perhaps, are the chief links used by nature for confining and fixing the substance of fire. What are pyrites in the mineral kingdom, but salts united with sulphur, which being also united with a few metallic particles, confine a great quantity of fire? In the vegetable kingdom, does not common fire disengage itself the more easily from wood, in proportion as that wood is deprived of its saline particles? The flame of wood, floated down rivers, burns clear, probably from the salts being dissolved by the water: and rotten wood, decayed by lying in moisture, emits light, by having lost the tenacious links of salts, by which the fire was kept imprisoned. In consequence of this dissolution, fire is become enabled to disengage itself by virtue of its expansive force, though too weak to affect our senses by heat. May not the loss of saline particles, in fish going into a state of putrescence, develope their constitutional fire, and occasion their luminous appearance? This light in wood, fish, or flesh, becomes extinct when exposed in vacuo, in extreme cold, and in spirits.

Sugar, and many other salts, have their fire expelled by rapid bruising: for fine sugar chewed in the dark will make the mouth luminous.

Fire may be instantaneously detached from dry air, and made visible, by tying a wet bladder over one end of an open cylinder of glass; drying the bladder, and putting an empty Florence flask under it, on the air pump: when the air is nearly exhausted in the dark, the bladder will burst by the pressure of the air upon it, and exhibit light on the flask, by the sudden derangement of that air which rushes into the vacuum.

FIRE, like all other material substances, is subject to be attracted by other bodies; by this tie some of its properties are obscured, and new ones produced. Like an acid, when saturated with an alkali, that cannot be distinguised by its taste, or any of its original properties: so fire loses with its liberty (when absorbed in other bodies) its chief property, the power of producing sensible heat. This power, however, is only suppressed, not destroyed; for it will again assume its wonted vigour, when the bond of union is broken by combustion, stronger affinities, &c. Fire is capable of condensation, as in gunpowder, pulvis fulminans, phosphorus, &c. Nitre, charcoal, and sulphur, are the ingredients of gunpowder. Nitre contains nearly ten times its bulk of vital air (which, from a retort may be expelled by heat). Charcoal is said, by Bergman, to contain ninety-nine parts in one hundred of inflammable matter, or, what I would call, concentrated fire. Here, then, are the two ingredients of inflammability; but what is to ignite them, and let loose their imprisoned fire? Sulphur; which takes fire more suddenly than most other substances, and must, therefore, be incorporated with the other two in the most intimate manner: powder-mills are for this purpose. From instantaneous ignition, the fire of the charcoal, and that of the vital air, burst into a flame, and if unconfined, would occupy 244 times the space they did in the granular state of powder; or displace 244 times their

bulk of air: or if the powder were confined in a space no larger than its own bulk, it would exert, by the repulsive force of fire it produces, an elasticity equal to 244 times that of the air.

Fulminating powder is a mixture of three parts nitre, one of sulphur, and two of fixt alkali: a powder that, being heated in an open vessel to melting, explodes with a loud report. Whilst heating, the nitre and sulphur melt together and form a nitrous sulphur: the acid of the nitre is attracted by the alkali, so the vital air of the nitre being intangled by their union, and inflamed by the sulphur, bursts from both with flame and explosion.

Phosphorus. This magazine of fire is formed from the bones of quadrupeds, birds, and fishes, long digested in vitriolic acid, and which yields microcosmic salt in great abundance. The union of this salt, with an equal weight of bruised charcoal, affords, by distillation, a considerable quantity of phosphorus. This concentration of fire is held so loosely by its acid, that a bare exposure to air (the other ingredient of inflammation) ignites it: hence it is kept under water. In a heat equal to 60°, it burns with a weak flame like sulphur, and can only be seen in the dark; but when exposed to a heat equal to 160°, or when that heat is produced by rubbing it between the folds of brown paper, it bursts into a vivid and destructive flame. Being made into crayons, we can write upon a wall with it, and read the writing in the dark, for every part of the letters produces real flame. Dissolved in oil, the face may be covered with it, harmless, though it has a frightful appearance in the dark. If a few grains of phosphorus, and an equal quantity of caustic alkali, be put into a small glass retort (having a long

neck), and with these a small spoonfull of water; if the retort be held over a candle, and the end of its neck be just immersed in water, the vapour, as it rises to the surface of the water, bursts into flame, and its smoke rises in phantastic rings to the top of the room. A grain of phosphorus, mixed with the same quantity of the oxygenated muriate of pot-ash, and laid on an anvil, if struck with a hammer will explode with a terrible report.

Many other substances produce light and fire by collision, and smell phosphoric, but have no other qualities in common with it, as phosphate of lime, tremolite, sugar, gum-elemi, black jack, and various resins. Two pieces of borax struck together produce a very strong white light.

The oxygenated muriate of pot-ash exhibits its fire by friction, and various mixtures: it is a salt, and produced by the bleaching gas, and a solution of pot-ash. The bleaching gas consists of

3 parts manganese,
8 parts common salt,
6 parts vitriolic acid,
12 parts water.

These ingredients are put in a stone retort, which is put in a water bath, and its neck luted into the side of the room in which is loosely hung the cloth to be bleached. All vegetable colours are seized and dissolved by the gas that issues from this retort, and by the liquor which subsides when the gas becomes condensed by the cold of the room. Coloured rags become white as snow; as well as paper of a dull colour, &c. Is not this from an affinity between the colours of solar light, and the oxygen or vital gas? If this gas be received in a large stone bottle, containing a strong solution of pot-

ash in water, the alkali will seize the acid gas, and the water will become strongly impregnated with a neutral salt. When this water is slowly evaporated, crystals will begin to shoot, which being collected and dryed, is the *oxygenated muriate of pot-ash.* If these crystals are not white, and pure, they may be dissolved again in fresh water, and again evaporated.

1. A pinch of this salt, mixed with as much sulphur, and rubbed in a stone mortar by a glass pestal, produces several loud cracks and vivid flashes of light. For the friction produces a heat sufficient to inflame the sulphur, which ignites the oxygen gas, and excites its latent fire.

2. If to two or three grains of the muriate a few drops of strong nitrous acid be added, and while they are uniting, a grain or two of phosphorus be dropt into them, vivid and beautiful flashes of light will issue from the mixture for several minutes.

3. Half a grain of the salt, and half a grain of phosphorus, rubbed in a mortar, produce various loud explosions.

4. One grain of loaf-sugar, rubbed with two grains of the salt, gives many reports; and if a few drops of sulphuric or nitrous acid be added, a flame rises from the mixture to a great height. The oxygen gas of this salt being so easily disengaged, a little caution is necessary in making experiments. Similar results to the above take place with charcoal, cinnabar, orpiment, cotton wool, oils of camphor, resin, &c.

The *fiery dragon* of the ancient alchemists is another instance of the production of spontaneous fire. If into an ounce of oil of tur-

pentine, or any essential oil, half an ounce of strong nitrous acid (dephlegmated by a few drops of vitriolic acid) be poured, a prodigious flame and thick smoke instantly arise! Essential oils contain much latent fire; which being dislodged by the acid (seizing the vegetable part of the oil), ignites with the contiguous air.

Homberg's pyrophorus is made by one part sugar, and three parts alum, to be melted, stirred, and dried on an iron shovel, till it becomes a blackish coal; when bruised, and put into a long-necked bottle, and the bottle into a crucible, filled up with sand, the crucible being kept red-hot an hour, or till a weak sulphurous flame has issued a quarter of an hour out of the bottle; when leisurely cooled, and corked close in another bottle, if a little of it be poured on brown paper, and breathed upon, it will take fire. Or a more compendious pyrophorus may be made by nearly filling a tobacco-pipe, with two parts calcined alum, one of powdered charcoal, and one of salt of tartar. These covered with sand, and kept half an hour red-hot, when cooled and knocked out will take fire; and if, on paper, wet with oil of turpentine, will burst into flame.

Fixt alkali keeps fire in a state of combination; breathing on it gives the alkali moisture, which detaches it from the fire; that fire having motion thus given to it, and, consequently, heat, that heat is sufficient to ignite the mass.

Pyrophori will not ignite in vacuo, though the containing tube be held in the flame of a candle; but if a little air be let into it, it will instantly ignite.

It is said that natural phosphori, in glow-worms, rotten wood, &c. will shine when covered with oil.

Heat is often produced where there is no appearance of combustion; and often the appearance of fire, when too weak to produce sensible heat: yet is fire never put into motion from a latent state, but it produces sensible heat in its extrication.

Mixtures that produce vapour, produce cold in the mixture, and heat in the vapour. Half an ounce of sal ammoniac, put in three ounces of spirits of vitriol, or marine acid; if a thermometer be put in the liquor, it will fall three inches; while another, held in the vapour, will rise. Hot coals, thrown into water, cools it for a moment; and the vapour is hot: for latent fire, when put into action, or expelled from bodies, always produces sensible heat; and the body is cooled from whence it is expelled.

SECTION III.

SALTS are every thing with a sharp taste, and soluble in water. *Sea*, or *kitchen salt*, is a combination of marine acid and marine alkali. *Luna cornea* is a salt formed by the union of silver in acid. *Verdigris*, salts formed by the solution of copper in vinegar; in reality, the rust of copper. *Ammoniacal salts* are an acid saturated with volatile alkali. *Sugar*, an essential salt, containing vegetable acid, combined with earth and oil. *Pot-ash*,

salt found in the ashes of vegetables. *Nitrous salts* are found in old walls, or places abounding with animal and vegetable filth; they are neutral, and produce nitrous acid and fixt vegetable alkali: all salts containing acid and alkali, are called neutral.

SECTION IV.

EARTHS make up the solid part of our globe; and under this name are included rocks, stones, mould, &c.; and though these are intermixed, and afford innumerable varieties, yet their components are—

1st. *Calcarious earths:* these are limestone, chalk, marble, stalactites (or stone icicles), * bones of animals, various fluors, gypsum, or plaister-stone, shells of fishes, and most earths that effervesce with acids, that fall in white powder when burnt, that will not melt into glass by heat, but will melt when mixed with borax, or calxes, and assist the fusion of lead, copper, and iron. Calcarious earth contains much fixt air, which, as well as the water the earth contained, is expelled by the fire of the lime-kiln: having thus lost two of its constituents, its cohesion is relaxed, and it becomes liable to crumble into a powder fit for mortar, and other purposes of building: water facilitates this; for slaking lime is but expelling the fire it imbibed and fixt while calcining; so the calx receives the water, its old friend, and expels the new. Quick-lime is caustic, and dissolves the flesh of a defunct in a few hours; this is from its strong attraction of fixt air, which it

* The calcarious earth of bones is united with the phosphoric acid.

tears from every kind of body that holds it with less affinity than itself. Lime-water also acquires a crust on its surface of real lime-stone, when exposed to the air; for there is fixt air in the atmosphere. Gypsum, or plaister-of-Paris, exposed to a moderate heat, parts with its water of crystallization: when after this it is made into a paste with warm water, and poured into a mould, that water, on cooling, becomes but barely the water of crystallization, and the plaister becomes solid in an instant.

Calcarious earth is supposed to be the wearing down of shells: from their sameness to the limestone masses found in all parts of the earth; from the shells on living fish growing lamina over lamina, till they become fifty or sixty times as large as the fish itself; from the fecundity of those fishes which throw off this stony incrustation; and the numberless generations that are extinct; it is not, indeed, improbable that a considerable part of our globe may be covered with their remains.

Calcarious earth being susceptible of extreme division, water which filters through its rocks carries off these fine parts, and depositing them on sponges, birds-nests, moss, bunches of vegetables, or any matter where the water can slowly evaporate, the fibres soon become covered with this stony incrustation, which assumes the shape of the body it covers; and such petrifactions are thought, by the vulgar, to be water transmuted into stone. Hence the stalactites, or icicle-shaped stones, impending from the roofs of caverns; the pyramidal spars, &c.

2d. *Siliceous earths* are flint and precious stones, as diamonds, rubies, topaz, opal, agate, quartz, gritstone, cornelian, jasper, &c. Many of these strike fire with, and even scratch steel: they

do not melt with the strongest fire, nor effervesce with acids; though they are acted upon by fluor spar. Alkalis dissolve it in the moist, as well as the dry way; i. e. by melting the earth and alkali together, in a crucible, when it becomes glass; or by digesting them, well bruised, with water.

Argillaceous earths are clays that harden in the fire, and are used for pottery; clay-marles that effervesce with acids, and moulder in water; boles, slates, or schistus, and mica. Alum is a combination of argillaceous earth with vitriolic acid. The most obvious characters of this earth are, its adhesion to the tongue, or any wet and soft body; its ductility and *kneadability*, by which it can be formed into earthen-ware, bricks, tiles, &c. these generally assume a reddish colour from the iron the earth contains, and a solidity from the flinty sand that vitrifies and holds the parts together while heating. Clays also include much water, which, being rarified in the baking, is apt to crack the clay; but if the water be leisurely expelled, the clay contracts in baking. On this property is constructed a * thermometer for measuring the heat of furnaces, by igniting a small cube of baked clay, of known dimensions, therein, and afterwards measuring its contraction.

Magnesian earth. This stone is remarkable for a soapy, greasy feel. Steatites is of this genus, of a greenish colour, and soft enough to be scraped with the nail. Soap rock, Spanish chalk, amianthus, Venetian and Muscovy talc, and asbestos, capable of being spun into threads, woven into cloth, and that cloth indestructible by fire, are all magnesian. Magnesia may be artificially made by mixing a solution of Epsom salt with an equal quantity of a solution of tartar (oil of tartar) in a glass, covering it with the

* Wedgwood's.

hand, and shaking them together, when the magnesia will instantly become solid in the glass: this shews, that the water, which kept each in a state of complete solution, was but just enough for the water of crystallization, when the salts came together. This earth, as well as the others, is capable of a vast variety of combinations and effects, which can only be enumerated in works written expressly on the subject of chemistry. After the crystallization of nitre, a thick liquor remains, which is called *mother water:* on pouring fixt alkali into this water, there falls down a white earthy precipitate, which, when washed and dried, forms the magnesia alba of the shops.

Zeolites are harder than calcarious stones; they melt easily in the fire, with swelling and ebullition; and dissolve with acids, without effervescence.

Barytes, or ponderous earth. This ponderous fossil is above four times the weight of its bulk of water, and is found in the neighbourhood of mines, or veins of metal; it resembles alum, but is of a striated texture, and is often found in the peculiar figure of a number of small convex lenses, stuck edge-wise in a ground. It decrepitates in the fire, melts before the blow-pipe, and fluxes dissolve it with effervescence. This stone, when strongly heated, exhibits a bluish light in the dark; but to make it a real phosphorus, it must be pulverised into powder, kneaded into a paste with mucilage of gum tragacanth, and formed into thin pieces, like the blade of a knife: these pieces are afterwards dried, and then strongly calcined in the midst of the coals of a furnace; they are then cleared by blowing on them with the bellows. In this state, if they are exposed to the light for a few minutes, and instantly carried into a dark place, they shine like glowing coals; even under water!

and though in time they become deprived of this property, it is restored again by a second heating.

GRANATE is a compound stone, often consisting of quartz, feld-spar, and schorl, mixed in a variety of shades. The paving stones of the streets of London consist of quartz and schorl.

SECTION V.

Metals.

PERFECT metals are those that cannot be decompounded, viz. gold, platina, and silver. *Imperfect metals* are iron, copper, tin, and lead, which, in fire, or strong menstrua, lose their metallic properties, become an earth, or calx, but which are revivable into their original metals by phlogiston, or fire. According to the new principles of chemistry, metals, in the act of calcining, imbibe oxygen air from the atmosphere, and thence become calxes, or oxyds: these oxyds are reduced (revived) by their oxygen combining with the charcoal of the fatty, or inflammable substances, heated with them, by which carbonic acid gas (fixt air) is formed, and flies off. The metal being thus left free, recovers its metallic or reguline form. Whether this, or the phlogistic doctrine, accounts for this interesting and curious phænomenon most rationally, must be left to the reader's judgment. That light, or fire, is one of the principal constituents of all vegetables; that this fire is capable of being fixt in them by charring in close vessels; that charcoal holds this inflam-

mable principle by strong affinity, and is not much disposed to part with it, even to the air, except that menstruum have its attraction reinforced by strong currents from bellows (see Optics). Do not the ores of metals imbibe this inflammable principle from the ignited charcoal in a furnace, and thereby become metals? for metals will burn and let out this inflammable principle, like any other combustible body. As fire repels itself, this principle can be forced out of the metal by great or continued ignition, and the metal again becomes an ore, or, which is the same thing, a calx: to this calx I conceive the vitriolic acid to have a stronger affinity; and, therefore, when iron is attacked by that acid, diluted, the inflammable principle is dislodged from the iron, and rises, with water, in the character of inflammable air, while the acid is seizing the calx, and forming with it the salt of iron (green copperas). This copperas consists of the calx of iron united with vitriolic acid, and if distilled in the common apparatus, Fig. 1, yields vital air, and the iron becomes revived, and is found at the bottom of the retort. Iron, also, acquiring more rust when exposed in large towns than on mountains, or in the country, from the acidity of smoke; that acidity qualifies the calx (rust) to produce vital air, when assisted with a little vitriolic acid, in the above apparatus. Do not these prove that vital air may be *generated* by acid and fire, as well as attracted from the atmosphere?

All other metals are liable to nearly the same routine of composition and decomposition, and, therefore, *fixt fire* may be said to be one of their most important ingredients.

Metals are all fusible, though at very different temperatures, and assume a crystallized figure in cooling; for if a hole be opened in the bottom of the melting-pot, after the surface of the metal has

become solid, and the fluid metal underneath be suffered to run out, the under surface of the solid metal will be curiously crystallized. This tendency to polarity, if disturbed, when the metal is passing from the fluid to the solid state, will make it assume a very different appearance and texture, to that which takes place when it cools gradually and in quiet; for even water in crystallizing, if stirred with a stick, may become solid, but it will not be like ice.

The affinities of metals to each other are various; some will not unite at all, others unite and combine readily: hence the use of solders. Tin unites pieces of lead; brass, gold, or silver, are solders for iron. Tin and copper unite in fusion, and make brass, &c.

Metals are mostly soluble in acids, with which, as above, they form salts; and act upon the metals as they would do upon any other combustible substance. If an alkali be added to a metallic solution, it seizes the acid, and the metal, so detached, falls to the bottom. But if a metal be put in the solution, to which the acid has a greater affinity, the acid will forsake its first connection, and unite with the second; hence the first metal becomes precipitated, and the second dissolved.

Gold is unalterable by art; is one of the heaviest of all known bodies (except platina); is capable of such expansion, that a grain may be beat into a leaf of fifty-six square inches, and the leaf itself be but $\frac{1}{282000}$ part of an inch thick; yet silver wire may be gilt, or covered, with a skin of gold that is not more than one-twelfth of the thickness of leaf-gold. Gold bids defiance to the utmost power of fire, so powerful is its attraction of cohesion; insomuch, that a wire of one-tenth of an inch in diameter requires 500lb. weight to break it. Reduced into powder, it is easily attacked by acids; but

its metallic nature is in no wise altered. Gold dissolved by aqua regia, and then precipitated by volatile alkali, washed, and suffered to dry in a cool place, exposed to a small degree of heat, explodes with a quickness and violence far exceeding gunpowder (see Combustion). A precipitate of gold from aqua regia is a true calx, and most metals precipitate it; lead, silver, iron, and copper, throw it down in its metallic state. Potable gold is gold taken from its solvent, by æther and essential oils; this liquor evaporated, leaves gold of the utmost purity, whose specific gravity is near twenty: Guinea gold is alloyed with copper, eleven parts gold to one of copper, so as to make its specific gravity only 17,75. Gold is found in its metallic state in most parts of the world, in lumps and grains, in the sands of rivers; sometimes bedded in earths or stones; when these are pounded and boiled with mercury, the mercury will unite, or amalgamate, with the gold, and may be easily separated from it by distillation, as the mercury will rise with a small degree of heat, and leave the gold.

Silver, the next perfect metal, fuses in a strong degree of heat (igniting before it melts), and is nearly as ductile as gold, though harder. In leaf-silver, it is three times as thick as leaf-gold. The fumes of sulphur tinge it black; and the sulphur will, in time, incorporate with its surface, and form a coating. The nitrous acid seems its natural menstruum, for it will dissolve half its weight of silver; and the solution is very caustic, corroding animal substances, and attacking whatever contains inflammable matter, seemingly with an endeavour to become revived. Fulminating silver is made by dissolving a very small quantity of pure silver in pale nitrous acid, and precipitating it by the addition of lime-water: this calx, or precipitate, after decanting the water, is to be dried by exposure to air and light three days: this dried calx being stirred, or agitated, in a solu-

tion of caustic volatile alkali, appears a black powder, from which the fluid must be decanted, and the powder left to dry in the air. This is the fulminating powder, which, when once obtained, can no more be touched! for the smallest agitation, any thing dropping into it, even a drop of water, will make it explode with a detonation, and destruction of every thing around it, to which a cannon is but as a squib! The theory of this terrible effect is much the same as that of fulminating gold. Copper will separate silver from its union with nitrous acid: if a drop of the solution be put on a small copper wire, between two small slips of glass, in a microscope, a beautiful forest will instantly rise from the copper, which is a precipitation, or crystallization, of silver, and called the Arbor Dianæ: for nitrous acid having a greater affinity to copper than the silver with which it was united, seizes the copper, and leaves the silver. A more palpable silver tree may be produced, by amalmagating four drachms of leaf-silver and two drachms of mercury into a paste. This paste must be dissolved in four ounces of pure nitrous acid, then diluted with a pint and a half of distilled water, and agitated; then preserved in a bottle, with a ground stopple, for use. When this preparation is to be used, about an ounce of it may be put in a two or three-ounce phial, and a soft amalgam of silver and quicksilver, about the size of a pea, dropt into it, and left at rest. In a few days, small filaments will spring out of the ball of amalgam, which will shoot into branches, and become a beautiful metallic tree.

Fifteen parts silver, and one of copper, melted together, is the standard of the British coinage. This metal is often found native, though generally mineralized; sometimes in masses, and often diffused through sand, ocre, or lime-stone; seldom pure: but the stones or earth, with which it is united, being pounded, and mixt

with mercury, the silver will amalgamate with the mercury, and leave the stones, or matrix, with which it was united, in the mine (for leaf-silver will amalgamate on the hand with mercury): now as mercury rises with so small a degree of heat, it is easily separated from the silver by simple distillation.

A wire of silver, one-tenth of an inch in diameter, will sustain 270lb.

Platina, or *little silver*, has yet been only found in the gold-mines of Peru and Mexico, and the discovery is of recent date: it is found in small angular shining grains, like clean steel filings, and is the heaviest body in nature; for when cleared from the irony sand which generally accompanies it, its specific gravity is twenty-two, and gold is only between nineteen and twenty. It will not melt in the most intense fire; though it has yielded to the focus of a large burning lens, and become a beautiful white, untarnishing, and malleable metal. It will weld like iron in intense heat; but rejects all acids, except aqua regia, or a mixture of the nitrous and marine acids. When dissolved in these, it is easily precipitated by sal ammoniac; and the sediment is then fusible, and capable of management. It also unites readily with most metals.

Was this extraordinary metal better known to society, probably it would be esteemed more than gold.

Mercury is always in a fluid state; and will not become a solid and malleable metal till cooled to the 39° below 0 of Fahrenheit's thermometer; it is then like silver, but more heavy, and a little more bluish. Though it is as indestructible by fire as gold and silver, it rises with less heat than will fuse any other metal; it is there-

fore easily distilled, and separated from the lead with which it is generally adulterated: but exposed to heat in tall vessels, it readily calcines into a red calx, called red precipitate; which calx may be brought back to its metallic state by a still greater heat: for as a moderate heat expelled its inherent fire, or phlogiston, from its surface (or qualified it to imbibe vital air), so when it is confined, a greater heat restores fire equal to what it had lost, and the metal returns to its original state. For though fire drives off the acid from sulphur, and unites with it, making vitriolic acid; that acid, in the character of a gas, and confined in a tube hermetically sealed, will, by long exposure in a sand heat, return to sulphur: shewing, that fire, though obliged to penetrate glass, can give to the acid all it wanted, to become what it was at first.

Mercury attracts water, and is seldom dry enough to be used for good barometers, till it has boiled several minutes in the tubes of those instruments. Thermometers should also be made with boiled, or distilled, quicksilver. Nitric acid attacks mercury, and dissolves it with violence: in this solution a considerable quantity of nitrous gas is disengaged, and it is said, that it is necessary that the acid should reduce the metal to the state of a calx, or oxyd, before it can act upon it; i. e. that one part of the acid should be employed in *disposing* the metal for solution, while the other dissolves it, in proportion as it is oxydated: and that all metals subjected to the action of vitriolic acid, have their surfaces, first oxydated by the acid, and then dissolved. This double operation, I think, is hard to prove: appearances are in favour of the acid attacking the metal at once. As it is but the calx of mercury that remains in the fluid, after the solution of nitrous acid and mercury has ceased; if marine acid be added to that fluid, it will seize the calx, and fall down with it

to the bottom, forming with it a caustic salt, called *corrosive sublimate:* but if to a solution of metallic mercury the marine acid be added, the compound which falls down is called white precipitate, and is similar to calomel or mercurius dulcis. As the causticity of metallic salts arises chiefly from the strong tendency which calcined metals have to return to their metallic state; corrosive sublimate, possessing this property in an eminent degree, becomes one of the most active of mineral poisons, by tearing from the stomach and intestines the inflammable principle so necessary to its reduction or revivification. Cinnabar is said to be the ore of mercury; though cinnabar may be made artificially by a combination of mercury and sulphur, and is the vermillion of the painters. Mercury is often found native, in small globules in the earth; and as it easily amalgamates with gold, silver, lead, tin, bismuth and zinc, it is also found in the character of a paste united with other metals. It is fourteen times as heavy as its bulk of water; and a cubic foot of it weighs 949 pounds.

Iron is the most useful to mankind of all metals (except when made into weapons). It is hard, malleable, exceedingly tenacious, ductile, and very light. It requires a most intense heat to fuse it, and is therefore brought into shape by a less heat, and hammering. A wire of $\frac{1}{10}$ inch thick will sustain 450lb. Its ores are various, sometimes like large pebbles, sometimes a soft red greasy pigment; there are whole mountains of iron-stone; the magnet is an ore of iron; indeed there is scarcely any thing animal, vegetable, or mineral, that does not contain iron; it is the most abundant of all minerals. These ores are prepared for smelting, by being broken into small pieces, roasted, washed, and mixed with limestone as a flux; baskets of charcoal and the ore, so treated, are alternately thrown down a chimney-like furnace, where a prodigious com-

bustion is provoked at the bottom by two pair of enormous bellows, actuated by a large water-wheel. The ore when fluxed, falls to the bottom of the furnace, forming a pond of fluid iron, which can be let out into sand moulds for pigs, pots, &c. This iron being far from pure, is carried to the forge, where it receives a white heat, and its impurities are beaten out by huge hammers, or squeezed out by large rollers; and thus condensed into bar-iron.

To turn iron into steel, the purest and most malleable is chosen and bedded in pounded charcoal, in a covered crucible, and kept several hours in a strong red heat. This is called cementation; which makes the metal more hard, brittle, and fusible than before; and if strongly ignited, afterwards, and plunged in cold water, it becomes fit for edge-tools, &c. The temper of steel is judged of by the prismatic order of colours, that appear on its surface, as it is slowly heating, viz. gold colour, purple, violet, deep blue, yellow, and then red; but if it be urged to excess, all the colours are expelled together, which makes the white heat, in which state it can be welded like iron or platina. Steel is heavier than the iron of which it is made. Must not this additional weight and additional hardness be derived from the charcoal? If charcoal (according to Bergman) be ninety-nine parts in an hundred phlogiston or fire, is it not this fire that made the ore into iron, and that iron into steel? and what is it but this fixt fire that is expelled in the character of inflammable air, when iron is attacked by the vitriolic acid?—is not the inflammable principle driven out by virtue of a more powerful affinity?

This metal rusts and corrodes when exposed to the air and moisture; by which it loses its fire, and tends to return again to an

ore: acid vapours facilitate this decomposition in large towns; acting upon iron something like the vitriolic acid, expelling the fire, and leaving the calx: for on high mountains, iron scarcely rusts at all. Rust may be revived like other calces, by treating it with what contains fire; for being steeped in linseed oil for some time, it will obey the magnet, and betray other signs of revivification.

Iron seems as if it were one of the most general products of organization; for it is found in vegetables which are merely supported by water: almost every mineral substance of this globe is coloured with it. It is with justice considered as the very soul of the arts. It is the basis of all black colours. Ocres and Prussian blue for painters are derived from iron. It also furnishes the art of medicine with many remedies.

Tin is a white metal, got principally in Cornwall: it is harder than lead; little sonorous; very malleable, though incapable of being drawn into wire. It can be hammered into leaves but one-thousandth part of an inch in thickness, called tin-foil. It melts long before it becomes red-hot; and, in that state, thin plates of clean iron (previously rubbed with sal ammoniac) dipped in it, become covered with a coat of tin, and are called tin-plates: sauce-pans, kettles, and many other utensils, are tinned something in the same way. In like manner it unites with, and adheres to, other metals, forming, with zinc, a much harder and less malleable compound, called pewter: lead is also used, which makes the pewter softer, and more unwholesome. With copper, tin unites in the crucible, and the compound is bronze, or bell-metal. Seven parts of bismuth, five of lead, and three of tin, form an alloy that melts in boiling water. Tin in fusion, soon acquires a calx on its sur-

face, which being ſkimmed off, fresh calx appears; and these calces are one-tenth heavier than the tin from whence they are made. These calces are revived into tin again when heated, with powdered charcoal in the same crucible; or the oxydation is prevented when powdered charcoal, or pitch, or grease, is thrown over the surface of the molten tin, and prevents the access of air. The calx of tin, as well as its finely bruised ore, is called putty, and used for polishing metals, glass, &c.

This metal is attacked by all the acids, and holds its fire, or inflammable principle, so loosely, that almost any of them will disengage it in the character of gas. If tin-foil be dipt in water, and a strong solution of copper in the nitrous acid be poured over it, and then the tin-foil be suddenly rolled up, and pressed together, a violent ebullition will ensue, that will burst into flame. On examining this effect, when cooled, copper will be found produced, and the tin reduced to a ragged calx. Is not this matter of affinity? Does not the easy fusion of tin, in comparison of copper, indicate that the basis of copper holds its inflammable principle with stronger affinity than tin? The basis of the copper (its calx) is only in the solution; the copper lost its fire in the act of dissolving in the acid, and is, therefore, greedy to steal that principle from any thing that contains it: tin holds that principle with a weak attraction; and it is torn from it with such violence by the calx of copper, as not only to produce the usual heat in such decompositions, but so as to break out into actual flame. Hence the tin becomes a calx, and the copper is revived.

This metal is the lightest of all others, being but seven times heavier than its bulk of water.

Lead is heavier than silver, much softer, very flexible, and incapable of being drawn into wire. It melts before it becomes red in the fire, and calcines easily, if air pass over it; first turning white, then yellow, and then red: this is minium, or red lead, which is made into wafers; and is a principal ingredient in the fine, dense, and white glass, used for achromatic telescopes; by refracting the rays of light more powerfully than the alkaline glasses. Lead acquires a crust by exposure to the air, which is a partial oxydation that protects the rest, and, therefore, it becomes a lasting cover for houses. It also acquires a soft crust by being exposed to the air, and the fumes of vinegar: this calx, when scraped from the sheets of lead (coiled up and exposed for that purpose), is ceruse, or white lead, used in oil painting. Ceruse dissolved in concentrated vinegar, affords a crystallizable salt, called sugar of lead, from its sweet taste, though it is a deadly poison. These calces are easily revived by giving them back what they lost in the act of calcination, viz. fire, or any thing that contains it. Hence, if charcoal, oils, fat, or any thing inflammable, be covered in the crucible with the minium, and exposed to a strong heat, the calx will return to lead. So, if wafers be burnt in a candle, the calx revives, and drops from the wafers in small globules of lead. A strong heat vitrifies the calx of lead into litharge, and a still stronger, into glass, which will run through the crucible like water through a sieve. This metal is eleven times and one-half heavier than its bulk of water.

Copper is a reddish, hard, sounding, malleable metal; capable of being reduced into thin leaves, and drawn into small wire. It is procured from ores of various forms and colours; some in the shape of brook-pebbles; some called peacock, and pigeon-neck ores, from

their likeness to the tail and neck of these birds: it is often bedded in hard rocks, or passes through them in regular veins, or seams. Sometimes a belly of ore (as the miners call it) is found, being a mass that fills the interior of a mountain. It is first roasted, to drive off the sulphur with which it is generally united; and broken, sorted, and smelted, in the usual way. Copper, so procured, is heated, and rolled into plates for use, or goes to market in small bars. Polished plates of copper exposed to heat, part with their light, or fire, in prismatic order; red being forced out where the heat is greatest, violet where the least, and the other colours playing, as it were, with the vibrations of the fire: copper, however, seems to have the strongest attachment to green light, and parts with it only by force: the flame of the fuel becomes a beautiful green; and in such a heat as would melt gold or silver the copper melts, and burns with whitish green flame; but a violent heat will sublime it in a metallic state. All the acids dissolve copper, but the nitrous with the greatest rapidity; much nitrous gas is disengaged, and the solution is of a beautiful blue colour: if a plate of clean iron be immersed in this solution, it becomes instantly covered with a skin of copper. On this property is founded the profitable mode of precipitating copper from the waters issuing from copper mines, which are generally impregnated with the vitriol of copper: bars of iron, placed in ponds of such water, not only become covered themselves with copper to a considerable thickness, but precipitate a great quantity, which is taken from the bottom of the ponds, and smelted. Is not this also matter of affinity? The iron becomes a calx; and the calx of copper becomes a metal. Does not the copper then commit a robbery on the iron? Does it not, by stronger affinity, steal the inflammable principle of the iron, and become, by that acquisition, a metal itself? While the iron so robbed becomes a soft calx, full of holes, without the least metallic

appearance! Copper becomes oxydated on its surface by long exposure to the air; a coating which protects the rest: this cover is very hard, and is the patin of the antiquarians, by which they sometimes fallaciously judge of the antiquity of medals and statues. Vinegar, when made to act hot or cold on copper, dissolves, or rather corrodes, it; this corrosion is the verdigris of commerce. The acid of common culinary vegetables, standing in copper vessels, performs the same effect in a degree; and hence the noxious, and even poisonous, consequences that arise from the use of copper utensils. The tinning of copper is meant as a protection to victuals, so exposed, from verdigris; but copper is never completely covered by tin, though it appears so. This operation is performed by melting the tin in the vessel to be tinned: this vessel is first well cleaned, and has any weak acid passed over its surface; the molten tin is then rubbed over its surface with rolled-up old rags.

Copper is used for large boilers; to sheath the bottoms of ships; and still for kitchen furniture, notwithstanding the above danger, &c. The salt of this metal is called blue vitriol.

Arsenic is a metallic calx, of a glittering whiteness, like sugar; has an acrid taste; and when thrown into the fire, or on an hot iron, smells like garlic. This substance is attached to most metals in the mine, is very volatile, and in great abundance; so that in working mines, it flies about, and being breathed by the unhappy miners, destroys their lungs. Arsenic is too much the instrument in the hand of wickedness, or imprudence, for anticipating death, by its likeness to sugar.

Cobalt, a semi-metal, is of a light grey colour; compact and

brittle; difficult of fusion; and refuses to amalgamate with quick-silver: it gives a blue colour to glass. Arsenic is forced from it by roasting under long crooked chimneys, in which the arsenic lodges, in sufficient abundance to supply commerce. When the oxyd of cobalt is cleared of its arsenic, it is known by the name of zaffar. This oxyd, fused with three parts sand, and one of pot-ash, forms blue glass. This glass pounded, sifted, and finely ground in mills, forms smalt; which is used in the preparation of cloths, laces, linens, muslins, thread, &c.

Bismuth is a semi-metal, of a shining yellowish-white colour, something like lead: it fuses with less heat than any other metal, except tin. It is found in various strata in the earth, generally combined with sulphur and arsenic. Nothing more is necessary in smelting its ore, but to throw it into the fire, and to have a cavity underneath to receive the semi-metal. The acids attack bismuth, and form solutions with it, but water precipitates it from all its solutions; and the precipitate, when well washed, is known by the name of magistery of bismuth, or white paint for the complexion. This pigment is easily converted into a metal by sulphureous vapours, or animal transpirations, and loses its colour. Pomatum, prepared with this magistery, turns the hair black.

Antimony is found sometimes native, in masses of shining irregular plates; sometimes in white crystallized fibres; but when combined with sulphur (as is common), it is of a dark bluish, or grey colour. Reduced to its reguline state, it is of a silvery-white colour; very brittle and scaly. Soon after ignition it melts, and as the heat increases, it sublimes in white fumes, which is the calx, or oxyd, of the semi-metal, and is used to give an hyacinthine colour to glass. All the acids dissolve it. Regulus of antimony pul-

verized, and mixt with twice its weight of corrosive sublimate, and then distilled, produces a thick unctuous matter in the neck of the retort, called butter of antimony: when water is added to this butter, a white calx falls down, called powder of algaroth, a most violent emetic. Equal quantities of antimony and nitre being projected into a red-hot crucible, a calx and alkali is the residue, known by the name of diaphoretic antimony: if a greater quantity of nitre be used in the projection, vitriolated tartar is found with the other products. This is the basis of emetic tartar, the principal ingredient in James's powders, and one of the first of medicines. Antimonial wine has long been used as an emetic. As the calx of antimony may be converted by heat into glass, and shaped as such, Spanish white wine, standing a few hours in such a glass, will become a powerful emetic. But this is a very uncertain medicine; for if the wine be more or less acid, the weather or room hotter or colder, an uncertain quantity will be dissolved from the glass; and it is, therefore, precarious and dangerous.

Zinc is a semi-metal, of a bluish brilliant white colour; difficult to be filed, hammered, or otherwise reduced to powder, but may be rolled into plates by the pressure of the flatting-mill. Calamine is the ore of zinc; a substance like lead-ore, and called by miners black jack. It is pounded, and, with powdered charcoal, put in large pots, and these pots in a furnace, like a common oven. These pots have tubes fixed in their bottoms, that pass through the bottom of the furnace into a vessel of water. After the tops of the pots are covered, and rammed close with clay, a strong fire is made around them, that fuses the calamine, which descends, in globules of zinc, through the tubes into the water. This is called distillation per descensum. Calamine, fused with copper, forms brass; and zinc and copper, melted together, makes pinchbeck, and other gold-

like metals. Zinc is attacked by the acids, particularly the nitrous and vitriolic; with the first, it produces nitrous gas; with the second, inflammable gas in great abundance. Zinc melts with a small degree of heat; but if the fire be strongly urged, it sublimes in a calx, like flakes of cotton, flying about the room, and is called philosophic wool. Dropt in grains, or filings, on a hot poker, it will oxydate in the same beautiful manner.

Manganese is a calx, and of various colours; in England it is generally black, and of a carious, broken, and rugged figure. It may be made into a metal, mixed with charcoal, and exposed to a violent heat, like other calces. The appearance of manganese is so various, that its change of colour by the blow-pipe is almost the only test by which to know it; the colour coming and going as it alternately becomes a metal, or a calx. If a globule of microcosmic salt, with a small portion of manganese, be fused together upon charcoal, with the blow-pipe, the colour will be a deep red. If the fusion be continued, by the blue part of the flame of the candle, the colour will disappear; but may be revived by softening the globule with the upper part of the flame. A little nitre added to the next fusion (as nitre calcines metals) restores the red colour; but inflammable matter will again discharge it. We have seen, in various instances, how charcoal, fat, and other inflammable matters, heated in the crucible with the calces of metals, revive them, and restore their metallic form and texture; the above effects are from the same cause: hence manganese is used in the glass-house to destroy the colour of glass. From the vast quantity of vital air produced by heat from this calx (see Lecture on Air), arises many useful and surprising effects: the bleaching compound has manganese for its principal ingredient: the oxygenated muriate

of pot-ash fulminates by the vital air of manganese: and if that which is called black wad be dried and kneaded with linseed oil, in a little time it will become hot, and burst into flame. Is not this also matter of affinity? Does not the vital air of the manganese solicit the inflammable principle of the oil to an union? for no flame can be produced without the union of these two ingredients.

Plumbago, or *blacklead*, is found in many parts of Europe, but most perfectly in the mountains of Cumberland. Its use in pencils need not be mentioned. It bids defiance to fire, and is, therefore, much used in the construction of crucibles. It protects iron from rust; and the bright appearance of fire-grates is from the plumbago, with which they are polished.

SECTION VI.

On Vegetable Analysis.

VEGETABLES and animals are organized bodies, very different from the mineral matters with which we have been hitherto conversant. They unite the powers of mechanism to those of chemistry, and have an apparatus of tubes and vessels, by which they elaborate, digest, separate, and concoct, the various juices that pass through them, in a style of the most sublime chemistry.

The organs of vegetables are chiefly tubes, calculated to extract and convey fluid matter from the earth and air, principally water;

which, obeying capillary attraction in the first instance, is thence raised and elaborated by the contractions and dilatations of ordinary heat and cold to all parts of the vegetable. The interior bark carries up the principal part of terrestrial and aqueous nutrition; the woody part may be hollow and rotten, while the rest is in vigour, by the good state of the bark: grasses, and many plants, also, are hollow. Earth, confined in tubs, seems undiminished by the growth of plants, though the plant increases in weight every month; water, air, and light, seem its principal constituents: but how these are transformed into the mucilage, sugar, oil, &c. found in analyzing vegetables, we know no more than how bread, rice, flesh, wine, &c. should form the flesh and bones of a human creature! The œconomy of animal and vegetable existence is obviously similar; and even in matters not very obvious: a thermometer, put in an augre-hole in a tree, will shew that the plant in winter is warmer than the atmosphere by many degrees; that the tree can resist cold by its moisture not freezing so soon as the water in its neighbourhood; that plants shut up their leaves and sleep in the night; betray irritability, sensibility, &c. &c.: but to enter into a detail of this curious subject, would carry me beyond the plan of this work.

VEGETABLE OILS. *Fat*, or *expressed oils*, are squeezed, or bruised, from the seeds of plants, as linseed, sweet almonds, nuts, &c. *Essential oils* are procured by distillation. If an aromatic plant be infused in water, or spirits, a few hours, and both together committed to the still, a spiritus rector of water and oil comes over into a close receiver, that contains the aroma, or odour, of the plant. The essential oil often swims on the water, and may be separated from it: a small drop of this oil will produce in spirit of wine the

essences called *lavender-water*, *rose-water*, &c. Fir, or pine-wood, cut into billets, and burnt in the middle, has a liquor expelled from each end of the billets, which is *tar*. Sometimes this essential oil is procured by burning the wood in close ovens, when the tar runs off through channels made for its conveyance. Tar dephlegmated, or boiled, to drive off any water with which it may be combined, becomes *pitch*. Pine, or fir, distilled, produces *oil of turpentine*, and an acrid phlegm, or water. This and other essential oils inflame with nitrous acid. *Camphor* is a concrete essential oil.

SOAP. Fixt alkali of soda, made more caustic by quicklime, and then put to olive oil, forms a mixture, which, in a few days, will acquire a consistency, to be put in moulds, and to be dryed for use. An acid will decompose the soap, by seizing the alkali: and hence hard water, i. e. water that contains selenite, will not lather with soap, because selenite contains vitriolic acid.

VEGETABLE SALTS are found in the ashes of plants. In boiling those ashes in water, the salts become dissolved by the water; and the refuse swims a-top, or sinks to the bottom; so the impregnated water is easily separated: this water evaporated, leaves the salts at the bottom of the vessel. *Soda* is from plants growing on the sea-coast; they are burnt in holes in the earth, so as to be in part fused, and, therefore, are in irregular lumps. *Pot-ash* is from the combustion of wood, and from an evaporation of the fluid which exudes from green wood when burnt to charcoal.

Gums are the mucilage of plants, forced through the bark when the sap is too abundant. We see little tears in cherry and plumb

trees; and the gum arabic of commerce is such an exudation from the acacia in Egypt and Arabia. They differ from resins by not being soluble in oil, alcohol, or spirit of wine.

Fermentation. Vegetables that abound with the saccharine principle, or sugar, afford, by fermentation, a spirituous liquor. Mucilaginous and glutinous principles are also found in vegetables: when mucilage is predominant, the product is acid; and when gluten abounds, ammoniac will be produced in the fermentation. But in all cases the concourse of air, water, and heat, is necessary to bring about fermentation.

Sap in plants often produces a plethora, breaking out of itself, and sometimes by incisions. In the spring, the sap in the body of the vegetable presents only a slight alteration in the nutritive juices; but in the summer, the whole is elaborated, all is digested, and then the sap possesses characters very different from those it possessed in the spring.

A rainy season opposes the developement of the saccharine principle, as well as the formation of resins and aromatics. A dry season is unfriendly to mucilage, but otherwise to resins and aromatics. Cold weather is inimical to all these, except mucilage, which is the principle of increase in the bulk of plants. Hence trees are most agreeable in their appearance in cold climates.

Ardent spirit, alcohol, or ordinary spirits, can only be got from saccharine vegetables. Sugar-canes afford rum; grapes brandy. The refuse of the sugar-works, mixed in a pond, or cistern, with water, go into a state of spontaneous fermentation. When that is over, the liquor is distilled, and rum is the product.

When the saccharine principle appears in ripe grapes, they are pressed, and the juice is received in vats; where, almost without stum, or yeast, it soon goes into a state of fermentation. The volume of the fluid increases, becomes turbid and oily, and fixt air floats on its surface. At the end of several days, these tumultuous motions cease; the woody and impure matters sink, and the wine becomes clear, and of a red colour. The wine, in this stage, grows warm, or otherwise the fermentation languishes, the saccharine and oily matters are not sufficiently elaborated, and the wine becomes unctuous and sweet. If rainy seasons produce a want in the saccharine body, the wine is weak; and mucilage predominating, causes it to become sour (the spirituous fermentation being scarcely perceptible). This defect may be remedied by adding sugar. If the wine be bottled, or put in close vessels, the gasseous principles are retained, and the wine is brisker. Tartar is necessary to the vinous fermentation, and it is in proportion to the abundance of the tartar; for wine, deprived of its tartar, ferments no more. Brandy is distilled from wine, or rather the lees of wine.

Apples contain a juice, which easily ferments, and becomes cyder. Pears produce perry; and from both, brandy may be distilled. Good wine is nearly one-fifth brandy, of proof strength; and when it is distilled with a slow fire, or the distillation repeated, spirit of wine, or alcohol, is produced.

The fruits of ours, and similar cold climates, afford little sugar; and hence to make wines from currants, gooseberries, rasberries, the sap of the birch, maple, &c. requires much sugar to be added to the little they naturally contain..

Malt liquor is generally made from barley: this grain contains a

tolerable portion of sugar, which has the glutinous part of the grain taken from it, by steeping in water, then laying it on a heap, and exciting the first stage of vegetation, in small germs, or sprouts. It is then dried on a kiln, and ground into a coarse flour, called malt. This malt is infused in hot water, in the mash-tub, and the sugar and mucilage become dissolved. This is called the first wort; which is again heated, and passed a second time slowly through the malt. The liquor is then boiled with a certain quantity of hops, which communicate a resinous bitter. It is then poured into a cooler, and mixed with yeast, or an acid leven, to accelerate the vinous fermentation. This soon takes place, and continues with warmth and ebullition for many hours, and before it quite subsides, the liquor is put in barrels, with the bung open for some time before it be closed. What then is fermentation? It seems to be the means ordained by nature, of separating the component parts of animal and vegetable bodies, when their vital functions have ceased; and to distribute those parts to the general mass of the elements to which they each belong: sending earth to earth; water to water; air to air, &c. Moisture and warmth are necessary to this process; for very dry substances do not easily go into a state of fermentation. This curious system of disorganization is generally divided into three stages: 1st, the vinous, or spirituous, fermentation: 2d, the acid, or acetous: and, 3d, the putrefactive. Animal bodies seem to pass the two first stages; and the first only takes place in vegetable bodies that contain saccharine juices. In these, a swelling and commotion first takes place; in time the grosser parts subside, and a clear liquor remains. Wines and malt liquors are stopt at this stage, by being confined in close vessels: but if left exposed to the air, the spirituous parts evaporate, and they pass on to the second, or acetous stage, by imbibing vital air, and become vinegar. If this spontaneous decomposition is suf-

fered to proceed, putrefaction takes place; the vinegar gradually becomes viscid and foul; an offensive air is emitted; volatile alkali flies off; and an earthy sediment subsides. The remaining liquor is mere water.

The death of plants is similar to the death of animals; the functions of both seem to depend on irritability, or the vital principle. When the vital principle ceases to operate, they are no longer subject to vital affinity, but to chemical affinity; by which, having lost their vital principle, they do not perish, but only lose their organic structure; and soon germinate again into other organized bodies.

To prevent fermentation in vegetable or animal substances, is but to change the proportions of their proximate principles, adding a greater quantity of those principles, that will unite with the bodies, and which are not themselves liable to fermentation. Hence vitriolic acid prevents wine going further into the vinous or acetous ferment. Animal matters are preserved in spirits of wine, common salt, or any salt. Such animal, or vegetable substances, *only* are considered as fermentable, which contain oil, or sugar; for the intestine motion of metals and acids is effervescence, *not* fermentation.

SECTION VII.

On Animal Analysis.

MATTER, when under the dominion of vitality, eludes the analyzing hand of chemistry. The vital principle must abandon its empire before the menstruum, or retort, can be used. The mineral kingdom is not governed by an internal force; it is subject to the action of external powers, so invariable, that the effect of fire, water, air, &c. is constant, and within the power of calculation. Though animal bodies are subject to the influence of external bodies, that influence can be so modified and varied by the living principle, that the chemist must look into the living body itself for effects, rather than in his laboratory. Yet in that laboratory has he found what airs are best to breathe; how to cure those that are noxious; what kind of water and other aliments are most conducive to health; and, thence, how to remove the noxious, and select the useful. In various disorders of the animal body, the vital principle seems to abandon the government of the parts affected, and to leave the solids and fluids to the destructive action of external agents; in consequence of which they become decomposed; and being destitute of the living principle, are subject to chemical analysis. But when this principle abandons the whole body, the same causes which maintained the functions of it, now begin to act upon the body itself. The gastric juice is separated by glands placed between the membranes which line the stomach, and from thence it is emitted into the stomach. This active menstruum is

the chemical solvent of food in the stomach; it forms it for digestion, by the lymphatic and lacteal tubes of the stomach and intestines: and when it has nothing else to act upon, it will attack the stomach itself, excite the sensation of hunger, and even dissolve the stomach after death. Small hollow balls, pierced full of small holes, and filled with flesh, bread, &c. have been swallowed, and suffered for a time to lie in the human stomach, and when drawn up by a thread attached to them, have been always found empty. This could not be by any mechanic motion of the stomach, for the balls were not injured; nor by fermentation, for neither air nor heat was produced; it must, therefore, be by the solvent power of the gastric juice. This juice, however, is different in different animals: when the balls, containing bread, were swallowed by a kite, or falcon, they were not dissolved, though flesh was: and flesh was not dissolved by the duck, or turkey.

Blood is that red fluid which circulates in animals by means of the arteries and veins. It supports life, by supplying the various organs with the peculiar juices they demand. It is generated in the stomach, and secreted from thence to the heart in the character of milk, where, joining the venal blood, they are propelled together up to the lungs, where they imbibe vital air and its heat, become red, and return, in that state, to the left ventricle of the heart. The blood, so augmented and purified, is now propelled through the arteries to the extremities of the body; and having distributed its heat and nutrition to the various organs in its passage, returns by the veins back to the heart a dark-coloured red. To renew this colour from the air in the lungs, and by that decomposition to seize its latent fire, the blood is again forced up to the lungs, &c. As iron is found in analyzing the blood, it has been supposed that it is made into a red oxyd, or calx, by the vital air

imbibed by the blood in the lungs. Air, no doubt, is some way the cause of its red colour. This humour is, with reason, considered as the focus of life; nay, by some, as being alive itself.

Blood distilled on the water-bath, affords phlegm, of a faint smell, and which easily putrifies; with greater heat, the product is acid, oil, and ammoniac, tempered with fixt air: a spongy coal remains in the retort, in which iron and sea-salt are found.

Blood, soon after leaving the vein, separates into serum, a yellow greenish thin fluid; and crassamentum, consisting of red globules, containing much iron.

Fat is a kind of oil, or butter, made solid by an acid, and contained in the cellular membrane. It is a deposit from the redundancy of food (by the wise provision of nature), to supply the want thereof. Fat, like oil, is not miscible with water; it forms soaps with alkali; and, from the still, produces an oil and an acid phlegm.

Milk is a mixture of oil, lymph, serum, and salt (detected by distillation). The union in this mixture is very weak, therefore easily destroyed, and the separation produces butter, cheese, and whey. Milk, viewed by the assistance of a microscope, appears like an infinite number of opaque globules floating in a transparent fluid. Milk is secreted by peculiar vessels in the female, for the support of her young; is very saccharine in the human species; milder and softer in the cow. When milk is left to spontaneous decomposition, like vegetable substances, it goes through the vinous, acetous, and putrefactive fermentation, though the first is scarcely perceptible; yet the Tartars catch it in that ſtate, and convert it into wine. The serous and oleaginous parts separate after stand-

ing some time, the cream rising to the top, and containing the fat substance called butter: by agitation, or churning, in the air, the fatty particles, striking against each other, stick together, and separate from the serous part with which they were united; which part soon turns sour, and contains a peculiar acid. Milk curdles with any acid; and, therefore, rennet, which is the infusion of the stomach of a calf, in water coagulates the milk: this property is owing probably to the gastric juice of the animal. The curd being collected, and the whey squeezed out, it becomes cheese.

Eggs very much resemble milk; the white differs little from the curd of milk; it coagulates with heat without losing weight; and evidently contains sulphur, by tinging the spoon with which it is eaten. The yolk, being the food of the chick, is an animalized emulsion, well adapted for that purpose. Oil, mineral alkali, and sulphur, are detectable in the eggs of birds.

Flesh. The animal muscle is formed of fibres, running lengthwise with the body; they are connected together by the cellular membrane, and enveloped in lymph, jelly, and fat. Their analysis, by distillation, affords little information: water, alkaline fluid, empyreumatic oil, ammoniac, and a coal, are the principal product. The digestor is, therefore, better than the still; for in a close vessel, half filled with water, over a slow fire, there follows a successive disengagement of the above principles, in the formation of soup. The lymph coagulates by the first impression of the heat, and appears in scum; which is taken off. The gelatinous part then becomes disengaged, and dissolving, incorporates with the water. When the water is sufficiently penetrated by heat, flat round drops arise, which, when cold, appear to be fat. As the digestion proceeds,

the mucous extractive part is separated; the soup now assumes its colour, and peculiar odour and taste, and salt takes off its insipidity. By this mode of cookery, the whole nutrition of the meat is preserved, its digestion is more easy and nourishing than roasted or boiled meats; for much of their nutrition is evaporated, and sent up the chimney, and the remainder is left hard, and difficult of digestion.

Skin and Bones. The parts of animals, whether membranes, tendons, cartilages, ligaments, or even the skin, bones, and horns, contain a mucus that is soluble in water, and known by the names of jelly, portable soup, glue, size, &c. The analysis of these parts is pretty much the same as in the last article.

SECTION VIII.

Chemical Apparatus.

TO effect the composition and decomposition of bodies; to separate the volatile from the more solid parts, &c. various utensils are required. For though copper and lead, united by fusion, may be separated by fusion, because lead will melt first, and run from the copper; and notwithstanding that the mixture of copper and zinc, called brass, may be decompounded by heat, as the zinc will assume the vapourous state first; and that quicksilver can be separated from gold, water from clay, &c. by the same process; yet

still these and thousands of chemical operations require apparatus, which we will now endeavour to give an idea of.

Retort, Fig. 4, is of glass, iron, or earth. Glass is the most cleanly; is not liable to be corroded; is impervious to air; and shews what is going on within. Such a retort, heated in water (called a water-bath), or in sand, contained in an iron vessel (called a sand-heat), is not liable to crack; but seldom can stand a naked fire.

Alembic, Fig. 5. This is a kind of still. The fluids to be separated are put into the long-necked bottle *a*, called a cucurbit; this is luted into the head *d*, which is fixed water-tight in the refrigeratory *m*, kept always full of cold water. To the neck, *e*, of the head, is luted the receiver, or bottle, *c*, called a matrass; these, all together, are called an alembic. When a fire is made in *b*, the volatile matter in the cucurbit rises into the head *d*, and becoming condensed by the cold water about it, drops into the matras *c*.

Air Furnace, Fig. 6. This furnace depends for its great production of heat to the height of its chimney. For the column of air, of which the chimney is a part, will be light in proportion to that height; and, of course, the colder and heavier air will rush through the fire with proportional violence, to restore an equilibrium; and combustion becomes more rapid and intense the more air is decomposed. *a*, is the ash-hole; *c*, the grate; *d*, a stone cover, to be taken off to place crucibles in the coals, or cupels in the current of the flame.

Reverberatory Furnace has the fire beaten down by a dome *a*, Fig. 7, on the top of the retort *d*, so that the retort becomes heated

on all sides. Sometimes the dome is filled with coals on all sides of the retort. *c*, is the ash-hole; *g*, the grate; and *m*, luted to the retort, is the receiver.

Woulfe's Apparatus, Fig. 8, is a method of distilling, by which the vapours that usually escape in the ordinary way are condensed, or arrested, in their passage through water, or other fluids. *a*, is a retort, containing the matter to be distilled; *b*, is the recipient; *c*, is a bottle with three necks, half filled with water;—the first neck has a crane tube luted into it, and its other end into one of the necks of *b*; the second neck has a tube open at both ends luted into it; and the third contains a crane that is luted into the other three-necked bottle *d*, which is half filled with an alkaline ley. When all their joints are well luted with lime and white of egg, and the fire put under *a*, the first product will rise into *b*; which, if it be gas, will be forced over the crane *e*, and through the water in *c*, which will arrest any fixt air that the gas may contain: the gas, on which the water will not operate, will then pass from *c* through the alkaline ley in *d*, which will arrest any thing acid contained in the gas; the remainder will then pass through the crane *g* into an inverted glass, as Fig. 1. The tubes, *x* and *z*, are only to prevent the bursting of any part of the apparatus, when the gas is generated with too much rapidity.

A blow-pipe added to these, will make a gentlemanly apparatus; and even a tobacco-pipe-head is very useful for experiments on a small scale.

SECTION IX.

Miscellaneous Observations and Experiments in Chemistry.

1. IF a solution of silver, in the nitrous acid, be exposed to intense sunshine, the silver will revive. Is not this because the calx of silver has a stronger affinity to light than to the nitrous acid?

2. The smelling-bottle may be made with a mixture of quicklime and sal ammoniac. *Explanation.* The sal ammoniac consists of marine acid (and sometimes the aerial acid, or fixt air), and the volatile alkali; which alkali is imprisoned by the acid, and totally without smell: but the aerial acid having a greater affinity to quicklime than the alkali, it becomes forsaken, and mixing with the air, affects the nose with its pungent smell.

3. Spirits, mixed with water, produce heat; mixt with snow, cold; (discovered by the thermometer). *Explanation.* Spirits certainly contain more specific fire than water; therefore, on their mixture, water and spirits having so great an affinity, they unite, and the superabundant fire becomes expelled from the spirit, active, and of course sensible, raising the thermometer. But snow is ice in a granulated state; and spirits help to liquefy it: ice melts by attracting latent fire from all bodies in contact with it (as formerly proved); and, of course, draws a portion of its heat from the thermometer immersed in it, sinks it, and thereby exhibits cold. It is well known that frozen flesh-meat thaws sooner in cold than in warm water: and two cakes of ice in the bottoms of two flat

vessels; if one be just covered with boiling water, and the other with cold, of equal quantity, there will be little or no difference in the time of their thawing; for the ice will soon assimilate the thin stratum of hot water to its own temperature. See page 24.

4. Mixtures giving out heat universally decrease in bulk; and those producing cold, will become larger than the sum of their two bulks. *Explanation.* The first mixture becomes less, by losing a portion of its latent fire, and, of course, that repulsive principle that set the particles at a distance. The second grows bigger by stealing fire from contiguous bodies, and thereby producing cold in them.

5. A piece of phosphorus in a solution of silver, copper, or other metal, soon becomes covered with metallic particles, or revived metal. Is it not the fire, or phlogiston, of the phosphorus that has restored the calx to its metallic state?

6. If fifteen grains of phosphorus be melted in a dram of water, and, when cold, if two ounces of vitriolic acid be put to it, beautiful fire-balls will dart from the mixture; but if oil of turpentine be poured upon it, the whole takes fire. *Explanation.* Vitriolic acid and water have so strong an affinity, that in uniting, their mutual fire becomes so disengaged, that the heat is sufficient to ignite the phosphorus. Strong acids seize the basis of inflammable substances, and expelling their fire, cause heat in some, and inflammation in essential oils, or other substances containing much latent fire.

7. *Liquor probatorius* is two ounces of quicklime, and one ounce of orpiment, poured into a pint and a half of boiling water, and

left to stand thirty-six hours: being carefully bottled, a drop or two in a glass of white or made wine will detect sugar of lead, by a cloud falling to the bottom of the glass. *Explanation.* Sugar of lead (a deadly poison) is a calx of lead, and becomes revived by the sulphur and arsenic of the orpiment.

8. If a thin small jar, *a*, Fig. 9, be half filled with good ether; and the jar, *c*, half filled with water, and placed under the receiver *z*, on an air-pump; when the air is exhausted, the ether will boil, and the water be frozen. *Explanation.* Water, and particularly light spirits, are kept in a state of fluidity by the weight or pressure of the atmosphere; remove the air, and they fly off in steam or gas; but in their flight carry off, and render latent, the fire in the neighbouring bodies. Hence the ebullition of the ether, and the ice of the water.

9. Cloth, dipt in a very dilute solution of gold, in aqua regia, and exposed to the sun, will appear like cloth of gold. *Explanation.* Light and fire being conceived as the same principle, if fire will revive metals, we also find that light will do the same, particularly when concentrated by a burning lens.

10. Manures act upon land in three ways: 1st, Mechanically, by increasing or diminishing the adhesion of the soil. 2d, Chemically, by diminishing adhesion by putrefaction; by decomposing metallic or earthy salts; by increasing or diminishing the capacity of the soil to retain water; by promoting the putrefaction of dead or dying vegetables; and by affording the salts and gasses, which are the pabulum of vegetables. 3d, Physiologically, by acting as stimuli on the living fibre of the plant; killing, by too

strong a stimulus, the weak and languid fibre, and exciting the stronger to stronger action.

11. Dried earth distilled, gives inflammable and fixt air in proportion to its fertility.

12. Limestone, chalk, marble, &c. it is said, will not calcine into lime, when inclosed in any thing that keeps the air from them. *Explanation.* Because in a close vessel their fixt air cannot escape, and the causticity of lime is from its want of fixt air, and the strong affinitive effort it makes to acquire it from substances that contain it. Hence, though lime contains no vegetable nutrition, yet, by tearing fixt air from all animal and vegetable substances that come in its way, these substances become dissolved, and mixing with other pabula, form the real nourishment of plants.

13. A silk handkerchief held in the middle of the flame of an iron furnace, will not burn. *Explanation.* Because air cannot get to the centre; it only has access to the outside of the flame, and combustion will not take place without air.

14. A strong solution of Epsom, or Glauber salt, in warm water, well corked in a bottle, will remain fluid; but on drawing the cork, the salts instantly crystallize, and become solid. *Explanation.* The salts and water are both in an expanded state, by heat, when first corked; and while no air has access to them, must continue so: but the instant they become liable to the pressure of the atmosphere (when the bottle is opened, the water being only sufficient for the water of crystallization), the particles of salt are

forced within the sphere of each others attraction, and instantly unite.

15. If several salts are dissolved together in the same water, when they crystallize, each particle will find its own kind, by a sort of innate polarity; i. e. dissolve half a pound of blue vitriol, and an equal weight of picked crystals of nitre, in separate quantities of boiling water; filter them together, while hot, into a flat bowl: when the water has evaporated a little, the crystals will shoot, the vitriol all together in blue, and the nitre in white crystals, the same as before they were dissolved.

16. Eight parts of bismuth, five of tin, three of lead, melted together, and a little quicksilver put to them while in fusion, make a metal that will melt in a handkerchief a few inches above a candle; and expands with heat more than any other metal.

17. That unseen aroma that transpires from plants, and is only sensible to the nose, constitutes the volatile character of the essential oils, and is of the nature of gas, from its fineness and invisibility. The slighest heat expels it from plants, and coolness condenses it, rendering it more sensible; and hence the odour of plants is most sensible morning and evening. This aura is so subtile, that though its emission from wood, leaves, flowers, &c. is continual, there is no sensible loss of weight. Yet it may be extracted and imprisoned, so as to constitute various essences. It is soluble in water, alcohol, oils, &c. and the infusions being distilled with a gentle heat, the aroma of lavender, of roses, of pimento, &c. may be preserved. This is the union of solar light with the finest particles of terrestrial matter; or rather it may be said to be

light itself, made sensible to the nose as well as to the eyes; for it is in the greatest abundance in warm climates, and is not produced in cold countries, but where vegetables are sheltered from cold, and exposed to the sun.

18. If powdered charcoal be strewed on strong nitric acid, a little heated, it will take fire. Is not the latent and concentrated fire of the charcoal disengaged by the acid seizing its base (the ashes of charcoal being an alkali)?

19. The *semen lycodii*, or witch meal, used in theatres to represent lightning, is almost impossible to be wet. This powder, strewed on the surface of water, not only swims without being wet, but prevents other bodies from being so, that plunge into water through it; so that a piece of money may be taken from the bottom of a bason of water without wetting the hand, as the meal descends with it. *Explanation.* May not this property arise from the great quantity of fire this very inflammable powder contains, which, forming a repulsive atmosphere round each particle, may push the particles of water so, as not to touch them?

20. A phial, nearly full of water, was hermetically sealed, and exactly weighed: the water was then frozen; in which state it was weighed again, and found lighter than when the water was fluid. Was not this by the contraction of the glass?

21. Extreme heat, and extreme cold, produce the same sensation. A Papin's digestor burst in the operator's face, and the sensation was that of extreme cold.

22. A green ink, that appears and disappears by alternate heat

and cold, is a solution of pounded zaffre in aqua regia, standing twenty-four hours, poured clear off, and mixed with an equal quantity of water: this kept in a phial, with a glass stopple, is ready to make the leaves of trees, and verdure of the ground, a summer or winter landscape. For if the picture be held near the fire (like the effect of the sun) the trees will become covered with leaves, and the ground with grass: but if taken into the cold, the verdure disappears, the trees lose their leaves, and the landscape is a winter scene. In like manner, if the ink is used in writing, the paper will seem a blank till it is held near the fire, when the writing will appear of a beautiful green: taken into the air, at a distance, and again it becomes invisible; alternately appearing and disappearing in this way for numberless times. *Explanation.* This ink is a solution of a green salt, that has such an affinity to water, that it can, when dry, attract a sufficient quantity of water from the air to become fluid, or deliquescent: when this water is expelled by heat, the salt appears; but it will soon acquire from the air a sufficiency of water to become again a solution, and, of course, invisible.

23. Sublimate of mercury, dissolved in hot water to saturation, crystallizes as it cools, like flakes of snow; and is capable (like the last experiment) of perpetual repetition. *Explanation.* All melted substances may be said to be dissolved in fire; or as fire repels the particles of matter to a distance, it renders the capacity of fluids to receive foreign matter greater; therefore solids dissolve in hot menstruums easier than in cold. But as in this case, where the fluid is supersaturated with the salt; in cooling the fluid contracts, the salts assuming the water of crystallization, concrete, and descend in little assemblages.

24. If shot and mercury be agitated together, in air, in a bottle, and the neck be immersed in water, the water will rise one-fourth in the bottle; if vital air be in the bottle, the greatest part of the air will disappear. *Explanation.* The agitation in air reduces the metals, in a degree, to a calx, or oxyd, which imbibes the vital part of the air.

25. A sympathetic ink is made by infusing one ounce of orpiment and two ounces of quicklime in clear water, and in an earthen pot, for twenty-four hours: this is called the first water. The writing ink must be one-fourth of an ounce of the litharge of silver, boiled a quarter of an hour in a quart of distilled vinegar; writing with this is invisible; but wiped over with a sponge wet in the first water, the writing appears like that with common ink. To make this ink penetrate through the leaves of a thick book, or even through a brick wall, red lead must be dissolved in the distilled vinegar. Writing with this on the title-page of a book, and wetting the last page with the first water; in an hour this water will penetrate many hundred pages without marking them, and revive the ink on the title-page! *Explanation.* So great is the tendency of a calx to be reduced to its metallic state, that it will attract phlogiston, or fire, through the most seemingly impenetrable substances. In this case, the calx of lead becomes revived by the sulphur and arsenic of the orpiment.

26. In burning a pound of alcohol, more than a pound of water is produced. Let *a b* represent an Argand's lamp, Fig. 10, with the alcohol in *a*, and the flame under the tube *c*, which tube is continued in a long worm through the refrigeratory *d*, filled with cold water. Now, while sixteen ounces of alcohol is burnt out of *a*,

seventeen ounces of water has dropped into the bottle *e*. *Explanation.* This water, we are told, is generated by the combustion of the alcohol. Here again am I under the painful necessity of setting up my opinion in opposition to that of one of the most candid, ingenious, and laborious chemists perhaps that ever lived. If the cause of truth did not fortify me against the diffidence I feel in differing from so great a name, I should sink under the presumption. In short, I think it is the decomposed water that existed previously in *that* air consumed by the lamp. The quantity of heat produced by this lamp, when trimmed with oil, is great; but the heat is intense when spirit of wine, or alcohol, is used; the quantity of air consumed by this lamp is, therefore, prodigious; and, of course, the quantity of water that must be detached from it: this decomposition of water must also be much increased by the great draught of air at the bottom of the tube *c*, which air will be destroyed by the flame, while the water it contained will fly up in steam, and be condensed into water again, by the cold worm, down which it descends into the bottle *e*. That water is in a state of solution in the atmosphere, is provable by numberless experiments; as well as that air is destroyed by combustion; is it any way extraordinary that a lamp so long, and so intensely heated, should consume as much air as would hold seventeen ounces of water in a state of solution?

27. Iron, in a white heat, thrust into a roll of brimstone, drops in round, black, striated globules, that are exactly pyrites. *Explanation.* Iron has the strongest affinity to the principle of inflammability; and sulphur contains that principle in great abundance; they form an union; and pyrites consists of sulphur and iron.

28. While fire separates the particles of bodies, and diminishes

their attraction for each other; it proportionably augments their attraction for contiguous bodies, by forcing the particles towards the adjacent body.

29. Ice melts in a heat of 40°, Fahrenheit's thermometer, as fast as in 212°, being the heat at which water boils: and water grows specifically lighter in cooling from 40° to 32°, the freezing point. See Lecture I.

30. When attraction (in due temperature) prevails in bodies, they are generally in a solid state. When fire prevails, they are in a gasseous state; so the liquid seems to be the medium between the two states.

31. It is probable that all the substances we call earths, are but metallic oxyds, irreducible by any hitherto known process: and even that the German idea, that chalk, kneaded into a ball with linseed oil, and exposed to a strong fire, may become a metal, is not groundless.

32. To form a curious impending metallic tree, of the revived calx of lead. Dissolve three or four ounces of the sugar of lead in a pint of boiling water; shake it at intervals, and in the course of the day filter it through three or four folds of filtering paper; and if not clear, repeat the filter through fresh paper: put the liquor in a wide-mouthed tall phial, and hang from its cork a piece of zinc, about the size of an hazle-nut, so that it may be just covered with the liquor. In a few days, a beautiful tree will have sprung downward from the zinc. *Explanation.* Zinc abounds with fire, or the principle of inflammability; it produces, with diluted vitriolic acid,

more inflammable air than any other metal. Sugar of lead is a calx of lead, caused by the corrosion of vinegar; this salt is dissolved in distilled vinegar, which, when evaporated, leaves the calx to shoot into long but weak crystals, of a sweet taste, and, therefore, called sugar of lead. This calx is revived by the inflammable principle of the zinc in shining leaves; while the outside of the zinc becomes itself a calx, having lost its metallic splendor and cohesion.

33. To revive limestone from its state of quicklime. In burning, the limetone loses two of its constituent principles, viz. its water, and its fixt air. The water it will regain by exposure; for it will attract a sufficiency from the air about it, and let go its acquired fire. But it wants fixt air to become the same sort of limestone it came out of the quarry; this, the human lungs can give to it; for, if a spoon-full of lime-water be put in a bent syphon-like glass tube, and the breath blown through it, the fluid will become muddy; the stone will be seen forming at the bottom of the liquor, which stone will effervesce with acids, and have every other quality it possessed in the quarry. For a portion of fixt air is thrown out of the lungs at every expiration.

Fig. 1.



Fig. 2.

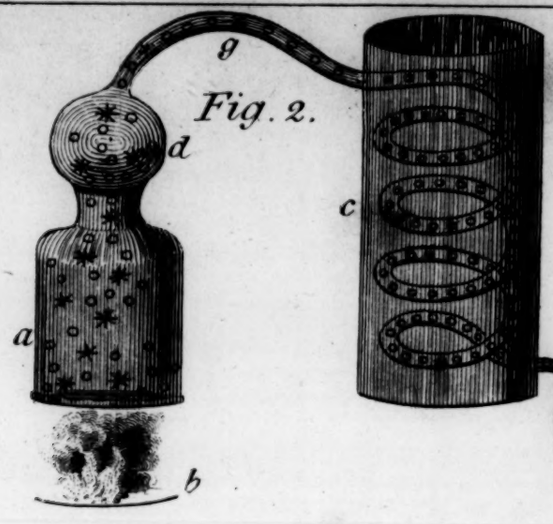


Fig. 3.



Fig. 4.

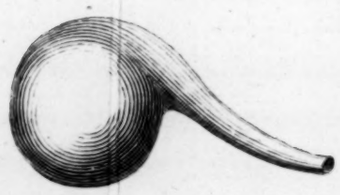


Fig. 5.

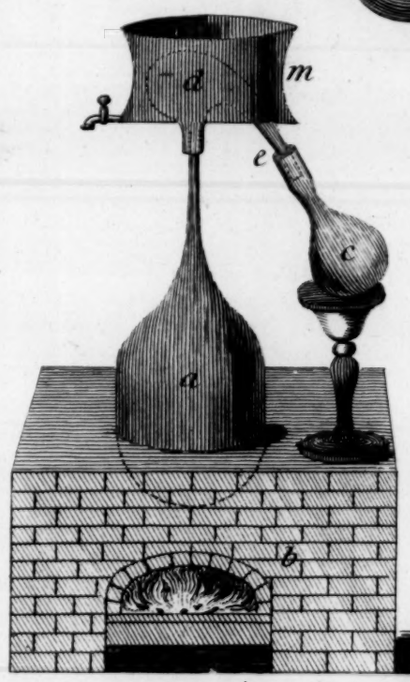


Fig. 6.

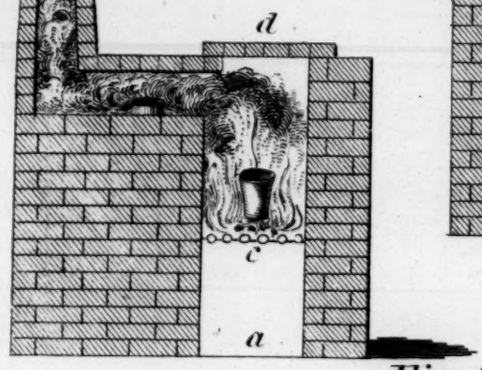


Fig. 7.

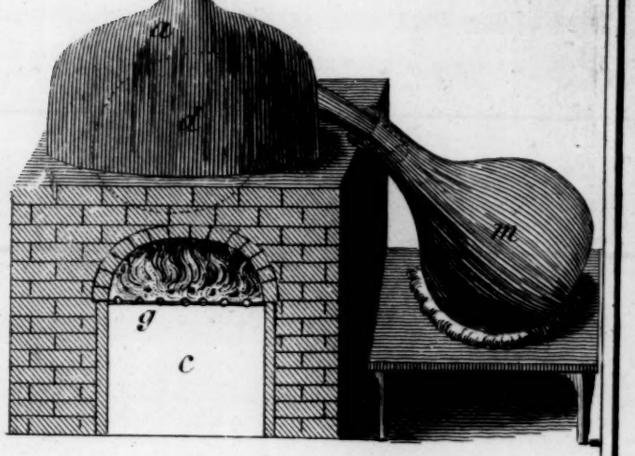


Fig. 8

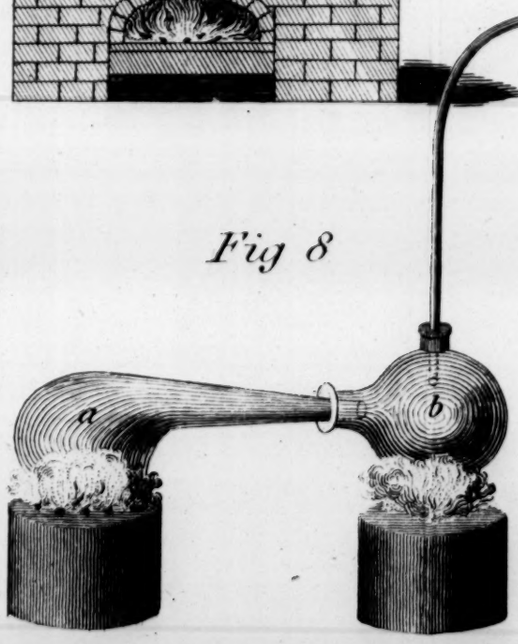
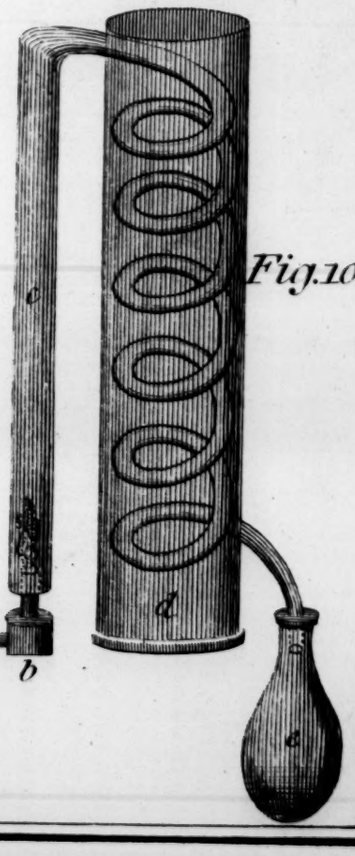
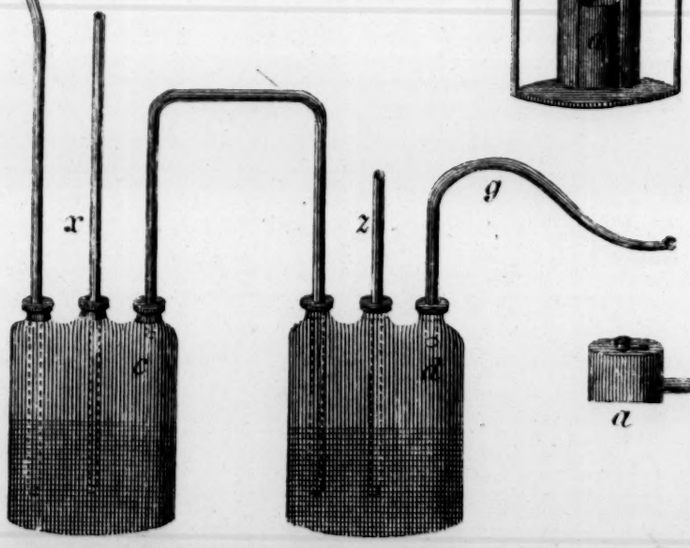


Fig. 9.



Fig. 10.





Barlow sculp

LECTURE V.

ON THE ATMOSPHERE.

Mechanical Properties of Air.

THE atmosphere is a thin fluid that surrounds our globe on all sides, like an immense ocean. We call it air: and it has the properties of grosser fluids; by resisting the motion of bodies; by sustaining floating bodies; by moving towards those parts that afford it the least resistance; and by excluding other bodies from the place it possesses. The air is necessary not only to the comfort and convenience of man, but even to his very existence, as well as to that of all other animals. Without the atmosphere neither dew nor rain could moisten the earth; nor could the sun impart his light to it. Yet is it principally made up of heterogeneous matter exhaled from the earth; a fluid in which the finer matter of all sublunary bodies is copiously floating. It is a vast laboratory, in which nature brings about an immense analysis; solutions, precipitations, and combinations. It is a grand receiver, in which all the attenuated and volatilized productions of terrestrial bodies are contained, mingled, agitated, combined, and separated. It is a chaos, an indeterminate mixture of mineral vapours, animal and vegetable

moleculæ, seeds, eggs, fire, water, light, meteors, &c. Perhaps it is the finest and most volatile parts of terrestrial matter dissolved in light or fire. It is an elastic fluid, capable of occupying a larger space than it naturally possesses; and also of being condensed, or squeezed, into a less space than it naturally possesses: and hence we find, that its particles repel each other; that this repellency, or elastic property, is occasioned by latent fire, or caloric (in the language of modern chemistry), diffused through, or rather united with, it; and, therefore, that its particles do not touch each other, nor can be brought into contact by any mechanical force, or the most intense degree of cold. To produce an idea of this repellency, suppose Fig. 1 a circle of particles of air, and the particle *e* a particle of fire with repellent rays, pushing the particles of air to a distance. The pressure of those particles towards one another, by means of their gravity towards the earth, balances the repulsive power of fire in common; but by an accession of active fire (that is, of heat) the power of the particle *e* is increased, and the surrounding particles of air will be pushed to a greater distance.

1. This is better illustrated by a tight bound bladder, half filled with air, held before a fire, when, in a few minutes, the bladder will be so inflated, as to burst.

2. If a bladder, full blown, have great weights laid upon it, it will be found to occupy less space than it did before the weights were laid upon it. In the first case, the repulsive power of fire had the superiority; in the latter case, its rays were mechanically pressed nearer the centre of the particle, and the particles of air brought also nearer together.

1. Into the bent tube *o*, Fig. 2 (shut at *c* and open at *n*), I pour

a little quicksilver (just enough to cover its bottom), then will the air in each leg be of the same density: but if I pour in a little more at *n*, its weight will condense, or squeeze, the air in the leg *c o* into less compass; but if I fill the leg *n* up to *s*, the air, which before occupied the space *o c*, will now only occupy the space *r c*; being diminished inversely as the weight; i. e. diminished as the weight is increased: for a double force presses the air into half the space; a triple force reduces it into a third of the space.

2. I inclose a bladder, half filled with air, with its neck closed, in a receiver, on the plate of an air-pump (as will be hereafter described); it remains flaccid, because the air within and without the bladder is of the same density: but when, by the pump, I draw the air from the receiver, and, of course, from the outside of the bladder; the air within, assuming its spring, inflates the bladder, as if full blown. See Fig. 3.

3. If an egg be divided in the middle, and its contents poured out of the thick end; if that shell be put under a small receiver on the air-pump, and the air exhausted, the film, or skin, of the shell will swell, by the expansion of the air under it, and make the egg appear as if it were become whole.

From these causes we understand why the air grows from a close and dense state, near the surface of the earth, gradually thinner and rarer, till, at a vast height, it may be conceived to degenerate almost into nothing. Conceive, in fleeces of wool piled upon one another, how the lowest may be compressed by those which lie upon it, how the next fleece will be less pressed, the next less than that, &c. &c.: and you will have a tolerably expressive picture of the progressive thinness of the air as we ascend in it. The difficulty of breathing

on high mountains, the oppression of the lungs in the ascent, and the fall of the quicksilver in the barometer, all indicate its increasing lightness; and that its weight on the surface of the earth is occasioned by the weight and density of that air which lies upon it.

If any height of the atmosphere be divided into a number of equal parts, as *s r*, Fig. 4, the pressure at 1 will be less than at *s*; and less at 2 than at 1, &c.; increasing in the ascent by an arithmetical series, as 1, 2, 3, 4, &c. But the descent of the quicksilver in the barometer will be in a geometrical series. So that the ascent into the atmosphere is arithmetical, while the fall of the mercury is geometrical; by which is calculated the barometrical method of finding the heights of mountains, &c. Thus at

Miles.		
$3\frac{1}{2}$	above the earth, the air is	2
7		4
14		16
21		64
28		256
35		1,024
42		4,096
49		16,384
56		65,536
63		262,144
70		1,048,576

times rarer.

Upon an average, and without an allowance for a small variation which the difference of temperature makes between the top and bottom of a mountain, about sixteen fathom is allowed, for the fall of one-tenth of an inch of the quicksilver in the barometer. So that if the quicksilver descends three-tenths in ascending a hill, it will be about forty-eight fathoms in perpendicular height.

This progressive rarity of the air arises from its gravity being, in some measure, counteracted by repulsion; for certainly this

ocean of air is held fast to the globe by the power of gravity, as well as the most dense body, as may be proved by numberless experiments. It is true, I feel no weight on my hand when I hold it out in this fluid; because the pressure under and above my hand is equal: but if I lay my hand on a hollow cylinder of glass, placed on the plate of an air-pump, and exhaust the air out of the cylinder, I become immediately conscious of something that presses my hand so forcibly to the glass, that I cannot release it. The prop is now gone; I have no pressure under my hand; a column of air, whose base is the size of the cylinder, and whose height is about forty-five miles, presses down my hand by its weight, and I must let in the air under my hand, with a stop cock, before it will be released.

In this experiment the hand undergoes a double sensation; besides being pressed against the top of the glass, its flesh is forced *into* the glass, by the spring of the air within the hand: for, though air may be said to lie latent, when it is a constituent part of our bodies; it instantly becomes active, when a vacuum, or a rarity, takes place on any part of the body, and forces out the skin, like a blown bladder.

2. I place a small receiver over the hole in the pump-plate; it is removable at pleasure, because the mass of air under it is of the same density as that which surrounds it. I now extract the air, and the receiver becomes so fixed to the plate, that I can lift the whole pump by it. What has fixt it? A column of air, whose base is the size of the bottom of the glass, and whose height is that of the atmosphere. This column presses the glass against the plate, and the air, under the plate, presses the plate against the glass; so that they

are held together by a mechanical force, as if I pressed the plate with one hand, and the glass with the other.

3. I weigh an empty Florence flask, capable of holding a wine quart, on a nice balance; the brass cap, cemented on its neck, has a valve of wet bladder, opening outward, so as to let air out, but to prevent any getting in. This flask, screwed on the air-pump, and exhausted, is then returned to the balance, and will be found to have lost about seventeen grains of its first weight; this, then, is the weight of a quart of air on the surface of the earth in our latitude: but it is heavier near the poles, and lighter near the equator, agreeably to what was proved in a former Lecture. This experiment is more correctly made by weighing the flask in water instead of air.

4. I immerse the neck of an empty bolt-head in a tumbler-full of water, and place both under a receiver on the pump-plate. On exhausting, the air rushes from the bolt-head through the water: for, when the air in the receiver becomes rarefied, the air in the bolt-head rushes through the water, to restore an equilibrium, thereby making visible the expansive property of the air. But now ten thousand bubbles of air appear in the water (air that was previously dissolved in the water); for, as the weight of the atmosphere is taken off from the surface of the water by the exhaustion, there is little obstruction formed to the repulsion which swells small assemblages of air so as to make them visible, and rise with ebullition to the surface of the water. This is one proof that water is a menstruum for air, and dissolves it. If then the air be let into the receiver, its pressure on the water will force the greatest part of the water up into the bolt-head. A bubble of air will pro-

bably remain in the top of the bolt-head; but as the water has had most of its air extracted, it will, in a few hours, seize the bubble in the bolt-head, and absorb it: another proof that water imbibes air. Fig. 5.

5. Why are receivers not broken by this pressure? Because of their globular figure, which presents an arch against it in every direction: but take a square thin bottle, with a valve, opening outwardly on its neck, and place it under a receiver on the pump, and exhaust the air (for by its spring it will come out of the bottle as well as the receiver); if, then, the air be let in suddenly upon the bottle, the valve will shut, and the bottle will be broken, with a loud report, by the pressure of the air on its outside. Fig. 6.

6. Having shewn that air is contained in a dissolved state in the pores of water, let us try if we cannot detect water in the pores of air. I screw a stop-cock into the pump-plate *c*, Fig. 7, and, on its other end, screw the brass plate *d*; on this plate I place the tall receiver *r*, and exhaust, or draw out, the air, as before. At the first stroke of the pump a dim cloud appears in the receiver, and falls in a regular shower on the pump-plate. Is not this the water previously dissolved in the air within the receiver, which, having lost its menstruum and support, coalesces and falls? Some are of opinion that this arises from the wet leather, generally put between the receiver and the plate: but when the air is excluded by wax, or the even surfaces of the glass and plate without any interposing matter, the precipitation of water still appears. If the stop-cock be now shut, and unscrewed from the pump-plate, the glass, the plate, and stop-cock, will all be fixed together by the pressure of the atmosphere. Immerse the stop-cock in a bason of water, and on opening it, a beautiful

fountain will instantly play to the top of the receiver, and continue boiling up after the small pipe *e* is covered, till the receiver is nearly full of water. This pleasing effect is produced by the pressure of the atmosphere upon the water in the bason; for all fluids incline towards that side which affords them the least resistance. Rivers run towards the sea, because they are less resisted on that side than towards their source. Water is forced into the tall receiver, because there is nothing in it to resist the pressure on the water; for we never commit these outrages upon nature, but she makes strong efforts to restore a level or equilibrium. But the grand intention, in this experiment, is to prove the air a menstruum or dissolver of water; and that the two fluids mutually imbibe, and enter into combination with, each other. I leave water in a vessel exposed to the air; in time it all disappears. What is gone with it? Believe not that it is annihilated or destroyed; nothing in nature is thus destroyed, or created; the original particles of matter remain unhurt as they came out of the hands of their great Maker; they are perpetually forming new combinations, uniting, dissolving, precipitating, and, to our gross senses, seem to change; but experiment informs us they are immutable. Where then is the water? Absorbed, soaked up, dissolved in the air; and, in due time, will be precipitated back on the earth in the character of rain, hail, or snow. This solution is most rapid when water is projected into the air in the character of steam; for steam is almost tangible, issuing from the spout of a tea-kettle, but is lost before it has got a yard from it. Where? In the atmosphere. For in that attenuated state (its particles separated by fire) it unites with air almost instantaneously. When water, in union with fire, assumes the character of vapour, the fire is held in a latent state, quite insensible, having lost its power of burning, and of giving

light. But when fire quits its latent state (how long soever it may have laid dormant and insensible), it always resumes its proper qualities and character, and affects the sense of feeling and the thermometer, as if it had never been latent. In lakes, rivers, on the ground, &c. evaporation is very slow, except assisted by heat; for heat separating the particles of water, or, perhaps, forming them into hollow spherules, they become specifically as light as air, rise into, and chemically unite with it, making one homogeneous fluid. Because evaporation takes place in vacuo, as well as in air, some object to this doctrine; for certainly, if a drop of water be allowed to rise through the quicksilver of a barometer, to its top, and be left there when the thermometer is even as low as 57, the drop in its evaporation will depress the quicksilver half an inch. But how is the doctrine hurt by this? Is the earth at any time so devoid of fire, that there is not enough which will attach itself to water, nay, even to ice? for ice will evaporate. If fire, in its latent or active state, or in the character of electricity, attaches itself to any kind of matter, it repels the particles of that matter, so as to make them occupy a larger space; as has been formerly proved. Its union with water forms no exception to this rule, whether it forms it into small globules; carries it up by making it specifically lighter; or becomes the medium by which air and water chemically unite. The particles of water, united with fire, no doubt will repel each other in vacuo as well as in air, so as to fill a space devoid of air. That heat increases the solvent qualities of fluids is evident, from the greater quantity of salt, sugar, tea, &c. that may be dissolved in hot than in cold water. For fire, in that case, is a part of the menstruum. The sea is more salt in the torrid than in the other zones; for the air will separate fresh water from the surface of a salt sea, as water, in distillation, will rise, with a small heat, sooner than salt: hence sea water comes over fresh in a still,

leaving the salt behind it. Evaporation is also in proportion to the quantity of surface: if two vessels, one twice the surface of the other (both being filled with water), be equally exposed to the air, the larger vessel will lose twice the quantity of the other in the same time, though the quantity of water in each was equal. Hence woody countries (from quantity of surface) produce more rain, than where the woods are cut down. Cultivation increasing the earth's surface by plants, leaves, &c. increases also the quantity of rain. The mouth of a bell-glass, of about twenty square inches, was placed on a new-mown grass plot, in very dry weather; its inside was soon covered with vapours, which were wiped from it every quarter of an hour, by a piece of muslin, previously weighed. After every wiping, the muslin was weighed, and six grains of water were collected every quarter of an hour. A square yard of coarse cloth was wet, and then exposed to a warm sun; it lost eight ounces of its weight in an hour. From these experiments it is easy to reckon that 1600 gallons of water would be raised from an acre of ground in twelve hours! Need we be surprized at the quantity of rain that falls? or at the size of the innumerable rivers that carry back that surplus to the sea, that is not wanted for the support of animal and vegetable life?

In the months of March and April, a wet cloth, exposed to the air, will dry in much less time than in the hot weather of July and August. Why? By the cold of winter, more rain falls than in summer: the air in spring is, therefore, less saturated with water than at any other time of the year; and, of course, more susceptible of carrying it off from any thing that contains it. Hence, in looking horizontally through a telescope at that time of the year, or on any hot day, the air seems in a quivering or undulating motion; but this appearance is not seen higher in the atmosphere.

This we conceive to be air and water in the act of uniting; for near the earth they are not so intimately mixed but that they break the rays of light differently, and occasion this tremulous motion. If this heat and undulation take place in the latter part of the day, and the cold, after sunset, seizes these vapours, before they are perfectly dissolved in the air, then they fall back to the earth, forming mists and fogs in low grounds; the dews of the morning; and the hoar frosts of winter. Vapour rising in such microscopic globules, as some represent, cannot refract or break the rays of light like a drop of rain; and, therefore, they make no rainbows, but only those undulations.

Vapour made by the breathing of large companies, is condensed on the sides of decanters filled with cold water; and on the inside of glass windows in winter; the vapour freezing, shews the polarity of ice in tree-like crystals, and beautiful foliage.

Stone pavements, walls of houses, wainscots, &c. in very cold weather, are deprived of a part of their heat: when warmer weather returns, fire enters these bodies, to restore an equilibrium of temperature, and leaves the vapours with which it was united on their outsides.

Evaporation is found to be in our climate about four times as much from the vernal to the autumnal equinox, as from the autumnal to the vernal. For heat facilitates all solutions. The greater the difference between the temperature of the air and the evaporating surface, the greater the evaporation; for if the air be colder than the evaporating surface, there will be scarcely any evaporation at all.

2. The degree of cold produced by evaporation is much greater when the air is warmer than the evaporating surface, than that cold which is produced when the evaporating surface is the warmer of the two; for vapour is dilated in proportion to the electricity it absorbs; and hence it is coldest in an exhausted receiver, where it dilates most. Warm winds, therefore, as the sirocco, harmatan, &c. are more drying than other winds.

3. Cold is increased by currents of air, or winds; for unsaturated air flowing constantly over the evaporating surface, and coming in contact with it, increases evaporation, and, of course, cold. Hence calm days are the hottest.

4. In winter, the earth at eighteen inches depth is warmer than the air; in summer, the air is warmer than the earth at that depth; for the earth is tardy both in receiving heat, and delivering it: at ninety feet it is nearly equal in winter and summer. Land imbibes eight or ten degrees more heat than the sea in summer; and is eight or ten degrees colder in winter.

That electricity has a great affinity to water, and assists its rise in vapour, is evident from many experiments. Two slips of leaf-gold, *c c*, Fig. 8, suspended in a small cylinder of glass *d*, with two small slips of tin-foil stuck to the inside of the glass at *o o*, is called an electrometer: if an hollow cap *n*, have a little water put in it, when a red-hot coal is dropt into the water, a vapour arises, and carries with it a portion of the natural electricity from the cap; the slips of leaf gold (by hanging from the cap) also having lost part of their electricity, separate with negative electricity, and restore what they lost by retouching the slips of tin-foil *o o*. See Electricity.

When vapours, by these powers, have risen into the upper and colder regions of the atmosphere, their parts will be still kept asunder by the repulsive power of fire and electricity; but electricity is drawn from its union with water by various means (as will be shewn hereafter), and then the vapours coalesce; little assemblages of particles get together, and millions of these obstructing the rays of the sun, are called clouds. Cold and winds assist this coalescence, and particularly the attraction which these little assemblages of watery particles have upon one another, by which, so many of them get together, that every assemblage now becomes specifically, or bulk for bulk, heavier than the air, and they begin to descend as drops of rain; but though slowly at first, they soon accelerate, by attracting some, and falling on other drops, increasing so much both in bulk and motion in their descent, that a bowl placed on the ground would receive, in a shower of rain, almost twice the quantity of water, that a similar bowl would on a neighbouring tall steeple.

Heat has certainly a great influence in suspending vapours in the air; and as we often see two currents of air moving in contrary directions, and probably of different temperatures, the warmer current will be cooled by the colder, and, consequently, dispose it to part with the vapours it holds in solution; hence rain will follow. Sometimes a cloud, just in the act of precipitating, will be arrested by a warm current of air, and dissolve and disappear, while we are looking at it.

As the air derives its heat from the earth (as hereafter will be proved), it necessarily grows colder and colder the higher we ascend in it; insomuch, that aqueous vapours are sometimes frozen before they become drops. In this case little icicles are formed

among the clouds, which, sticking together, form those flocculent masses we call snow.

Hail-stones are drops of water frozen in their descent. In general they are round and small; but attracting, (and falling on each other in their descent, many stick together, become angular, and sometimes large enough to break windows, &c.

The disposition of the atmosphere to retain or part with its vapours, is best indicated by the barometer, Fig. 9. This instrument is a tube of glass, about thirty-four inches long, shut at one end (or hermetically sealed, as it is called), and open at the other; this tube is filled with clean quicksilver, and warmed so as to drive out any bubbles of air that may lodge unseen within the glass, and with a finger on its open end, it must be inverted in a bason of quicksilver; then will the quicksilver fall from the top of the tube a few inches (leaving the space above a perfect vacuum), till it becomes a counterpoize to the weight of the air pressing on the quicksilver in the bason. The height at which the quicksilver in the tube stands above that in the bason, must now be measured; perhaps it may be thirty inches; then must a scale of three inches be divided into tenths, viz. from twenty-eight to thirty-one, and fixed on the frame to which the tube and bason are fastened: for, in our climate, the quicksilver seldom rises above thirty-one inches above the bason, or falls lower than twenty-eight inches. When the air is in an heavy and permanent state, susceptible of retaining vapour in a state of solution, it presses the mercury up, perhaps, to 30 or 30.5. When lighter, and liable to let the vapours coalesce, it presses light on the quicksilver in the bason, and that in the tube falls, perhaps, to 28.5; then do we look for rain or wind. But in *our* insular situation, the changes in the weather are so frequent

and sudden, that this instrument is not so prophetical as on the continent. In order, however, to make it as prophetical as we can, we should observe the top of the quicksilver in the tube; if it appears convex, it is going to rise; if flat, or hollow, it is going to fall. For it will rise and fall in the middle, when the attraction of the tube will keep it stationary at the sides; and it is the sides we generally look at, and fix the indexes to. All fluids flow through themselves easier than through pipes of any kind; even a drain in a field ought to be deeper than it commonly is, that the water may flow over itself.

To construct a barometer really indicative of the approaching weather, I made this alteration in the wheel barometer, Fig. 10; the tube is bent, and open at its short end. When the tube is filled, the quicksilver will rise in the short tube to *c*, on which a glass ball swims, a little heavier than the weight *n*. As the air grows heavier, it will force the mercury down at *c*, and make the index rise. As it grows lighter, the quicksilver will rise at *c*, and depress or sink the index. Now, as the scale has two inches to represent one, the ball *c* falling half an inch, will produce two inches on the scale, and the least swell, or depression, of the quicksilver at *c*, will be amply indicated on the scale. The scale gives a better idea of rising and falling than a wheel; all the parts are concealed, except the scale and index; so that none is liable to be broken: and the indicative part is at the bottom instead of the top, and, therefore, more conveniently seen.

7. That it is a variation in the weight of the air that makes the quicksilver rise and fall in the barometer, we thus prove. We put a plain barometer under a tall receiver, on the air-pump, as

Fig. 9. On taking out the air, the quicksilver begins to descend, and would all fall into the bason, if the exhaustion was complete: but on letting in the air, it rises to *o*, its first situation. If the air in the receiver be condensed, the quicksilver will be forced up to the top of the tube.

8. Though it is needless to exhibit any further proofs of the air's gravity and pressure, yet its forcing quicksilver through the pores of wood, is too elegant an experiment to be omitted. A willow stick is fixed in the bottom of a small tun-dish *c*, Fig. 11, which is placed on the neck of a bottle, so as to stop it, and prevent any air from getting in; quicksilver is then poured into the dish, and the air extracted from the bottle; the air's pressure upon the quicksilver forces it through the pores of the stick in thousands of beautiful streams. A hole is made in the bottom of the bottle for the air to go through, with a knob over it, to prevent the quicksilver from falling into the pump.

9. We have not yet estimated what, or how much, this pressure is. I take two hemispheres, whose diameters are three inches, and their area seven square inches, Fig. 12. I screw the lower on the pump, and put a wet piece of leather between it and the upper, as Fig. 12, then draw out the air from between them, and turn the cock; by this means, they become fastened together, with a force that is equal to the weight of a column of air, whose base is seven square inches, and height forty-five miles. To try how much this force is, I screw the stop-cock *c* into the board *d*, and applying the steelyard, *r*, and weights, I find it requires upwards of 100lb. to pull them asunder! so that 100lb. is the weight of the column of air *G*, supposed to be forty-five miles in height, and seven inches square at

bottom: or about 15lb. upon one square inch of the earth's surface!!

Many of these effects may be attributed to what is vulgarly called suction: but we deny the existence of any such principle. The pressure or spring of the air accounts for every thing that has the appearance of suction.

1. I place a small receiver on the leather of the pump-plate, at a distance from the hole from whence the suction may be supposed to proceed, and pour a little water round it. Over this receiver, and over the hole, I place a large receiver, capable of covering both at a time, Fig. 13. On exhausting, I see air come from under the small receiver, by the bubbles it makes in the water, and yet, when I shake the pump, I find it is quite loose; while the large receiver is so fixed to the plate that I can lift the pump by it. Why is not the small receiver fastened? I *suck* the air out of it as well as the large one, yet one is fast and the other loose. I now let the air into the large receiver, and the tables are turned; the small one is fixed, and the large one released. Can this be suction? The small receiver was fixed after the suction had ceased! The fact is, that having taken the air out of both, the large one must be fixed, by being exposed to the pressure of the outward air; but the small one could not, because there was no air on its outside to press it down: but when the air was let in upon it, and was not able to get under it so fast as it wrapt round it and pressed it down, it became fastened by the same means that released the other. See Fig. 13.

2. A boy fastens the end of a string in the centre of a round piece of wet leather, Fig. 14; he then presses the leather on a flat stone, and by pulling at the string he lifts the stone, thinking

it is sucked up by the leather. No, no, my young Tyro, when you become a little better acquainted with philosophy, you will find it done by the pressure of the atmosphere. You press the piece of wet leather to the stone, and by pulling at the string, you raise up the centre of the leather, and make a vacuum under it; then will the air endeavour to get into the vacuum, and press the edges of the leather against the stone, and the stone against the leather, with a force equal to the weight of an ordinary pebble. See Fig. 14.

3. The instrument called a transferrer, explodes the doctrine of suction still more effectually. I screw the apparatus, Fig. 15, into the pump-plate, by the stop-cock *c*, leaving the cock *d* open, and *e* shut. On exhausting, I fasten the glass *g* on its plate, but the receiver *n* is loose. I then disengage the whole apparatus from the pump (first shutting the cocks *c* and *d*), and then can fasten the glass *n* on its plate, by opening the cock *e*, and both can be turned down without fear of falling on the floor. Why? The receiver *g* is exhausted through the channel of the transferrer, and the cocks *c* and *d*, as effectually, as if it stood on the plate of the air-pump: but when this apparatus is disengaged from the pump, and the receiver *n* is placed on its plate, and a communication is made between the insides of the two receivers, by opening the cock *e*, the air in *n* rushes through the cocks to restore an equilibrium with *g*, and becomes, in a degree, exhausted itself; for it divides its air between its exhausted neighbour *g* and itself, and thereby becomes subject to the pressure of the atmosphere; depositing a shower of rain, in parting with its air, and becoming fixed to its plate. Could *n* be sucked down, when all suction had ceased, and the whole apparatus was removed from the pump?

4. The common household pump assists in exploding the idea of suction; for we prove that water rises in it by the pressure of the atmosphere on the well. Fig. 16 is a sucking-pump; *s* is the cylinder of wood, or metal, in which the piston *r* works. In this piston, there is a trap-door, or valve, opening upward, that will suffer water to rise through it, but when shut, will prevent its return. When this piston is drawn up by the pump-handle, or lever, *t*, as high as *s*, it lifts the column of air that rests upon it, and would have left a vacuum between *r* and *s*, if the air below did not, by its elastic spring, endeavour to restore an equilibrium; and, by that means, render the air below *r* thinner, within the pump, than it is without. Hence a difference takes place between the pressure of the air within the pump, and that without; of course the pressure on the well being greater than that within the pump, the water will be forced up the tube through the valve *u*, which valve shutting, by its own weight, will retain the water so raised, both above and below it. The next stroke of the pump-handle will raise the water a little higher; the lower valve still retaining the water that has risen through it; and so on, till the water has risen to the height of thirty or thirty-two feet, when it stops, and no action of the piston, above it, can raise it further. Why? Because a column of water of thirty, thirty-one, or thirty-two feet high, is equal in weight to a similar column of air of forty-five miles high. Is it not the pressure of the atmosphere, then, on the well, that forces the water up the pump? and instructs us, That a piston must always work within these heights, above the surface of the water?

But let us try, if water will rise in a pump by suction, when there is no air to press upon the well. Fig. 17, *a*, is a pump of

the same nature as that above; it is screwed tight into the plate *b c*, which covers equally tight the open receiver *d*. While the air has free access to the water, in the cup *o*, if the pump be worked, the water will rise. But now I place this apparatus upon the pump-plate *e f*, and exhaust the air from the receiver, and of course from off the water: if the pump be then worked with the utmost violence, not a drop of water will rise.

5th. The sucking of a child seems favourable to the doctrine of suction. But the rarefaction within the child's mouth, and the pressure of the air on the nurse's breast, are the causes by which the nutritive aliment is forced into the child's mouth: for the human mouth is a natural air-pump. If the tip of the tongue touch the teeth, the cheeks cannot be sucked in between the teeth; but when the tongue is drawn back, the air is condensed behind the tongue, and rarefied before it, so that the air without, forces in the cheeks between the teeth. The cavity of the mouth may, therefore, be considered as the barrel of an air-pump, and the tongue as its piston. A child, by instinct, draws his tongue backwards and forwards, keeping up a continued rarity in the forepart of the mouth, and the pressure of the air on the breast, forces the milk into that rarity. If a cupping-glass be screwed to a small syringe, and placed on the cheek, and the syringe be worked, the flesh will be forced into the glass, and both the glass and syringe will hang on the cheek; this experiment also confutes the doctrine of suction.

6th. Breathing may, in some measure, be said to be dependent on the pressure of the atmosphere. Between the thorax, or chest, and the abdomen, or belly, there is a fleshy flat partition, called

the diaphragm, or midriff. By the involuntary action of the *intercostal* muscles, this diaphragm is made to rise and fall in its centre, thereby alternately increasing and diminishing the cavity of the thorax; and, consequently, alternately rarefying and condensing the air among the vesicles of the lungs. When the diaphragm descends, the air in the thorax becomes rarefied; and to restore an equilibrium, the outward air rushes through the mouth and nose into the lungs, and we are said to *inspire*. But on the rise of the diaphragm, the air (as it were) is squeezed out, and we are said to *expire*. This operation going on from the moment of our birth, we cease to feel this mechanism sensibly, long before we are capable of observing or reflecting upon it. Hence breathing seems to us spontaneous; as if no mechanism was concerned. The lungs are innumerable bladders, very small and long, impending, as it were, from the windpipe; and similar ramifications of blood vessels rise up among them; so that the air and blood vessels intermix, like the fingers of the right hand, put in between the fingers of the left, lengthwise: wonderfully convenient for bringing about that purification which the venal blood receives, in its passage through the lungs. For, after the blood has been forced through the arteries, by the contractions of the heart, and has returned to it again through the veins, and has also received an addition from the food, through the lacteals, it makes a digression from the general circulation, up to the lungs, and is rather thick, and of a dark purple colour, occasioned by its loss of the caloric, or fire, it derived from the air, and the quantity of fixed air that united itself with it, in its passage through the body. Here the blood undergoes a surprizing change; it almost instantly becomes of a beautiful red colour, and so thin, that, on its return to the heart, it can be forced

through the finest capillary vessels. Whence arises this change? Undoubtedly from the air. For, as the air and blood vessels intermix, and touch with such a quantity of surface, they exchange qualities with the utmost facility; the blood imbibing the oxygen, or vital part of the air, as well as its latent fire; and delivering to the remaining air the fixed air, and other mephitic gas, which makes the expired air azotic, and unfit to be respired again. The blood so renewed and purified in the lungs, returns to the heart alive, and being by that muscle forced again through the arteries, it distributes nutrition and heat through every part of the body. Returning again through the veins, it is again sent by the heart up to the lungs, &c. &c.

That this is the real œconomy of this part of nature, is provable by many experiments.

1. Blood placed under a bell-glass, filled with vital air, will remain florid, and without alteration for many days; but blood exposed to common air soon changes, and becomes putrid.

2. I put the short end of the crooked tube *c*, Fig. 18, into the inverted glass *d*, and immerse both in a large bason of water; by applying the mouth at *e*, I can breathe the air in the glass *d*, without any mixture of outward air. When the air has been half a dozen times in my lungs, I take the crane *c* out of *d*, and put a lighted candle into *d*, which is instantly extinguished. If I then put a live bird into it, the bird is soon convulsed and dies! for air that extinguishes flame is fatal to all animals that breathe air. Therefore a candle should be fixed to the end of a long pole, to try the air in vaults, caverns, places long shut up, &c. before they are entered. In the above experiment, the vital air is absorbed into

the blood, and diminished in bulk; its azote and a little fixed air is left in the glass; but if to this azote one third of its bulk of oxygen, or vital air, be added, it will become atmospheric air again, in which a bird will live, and a candle burn, as in common air before. From this, and other experiments, it appears to many that the general mass of the atmosphere consists of two kinds of air, viz. about one-third of oxygen gas, or vital air; and two thirds of azote, or poisonous air, that will neither support fire nor animal life. Other experiments that favour this hypothesis are:

1. If a piece of tinder be fixed to the end of a small wire, and, when ignited, be plunged into a two-quart jar, filled with vital air, the iron will burn with a vivid flame, and dart out sulphuric sparks of a most effulgent brightness! While this beautiful extrication of light from the iron is going on, the air will be observed to diminish, and the little globules of oxyd, or rather finery cinder, that drop from the iron, will be found to have increased in both bulk and weight above the iron so burnt; it is even said that the increased weight is exactly equal to the weight of the air which disappears in the operation: the remaining air in the jar will be found rather worse than atmospheric air, or approaching to azote. This beautiful and striking experiment is generally exhibited to prove, that metals change to an oxyd, or calx, only by imbibing the vital air; reducing that air to a solid with the oxyd; thereby increasing the bulk and weight of the oxyd above that of the iron, and also proportional to the diminution or loss of the air. Hence, say they, this very vital air may be expelled from the oxyd by heat or a strong acid in the chemico-pneumatic apparatus, and the calx, or oxyd, reduced to the very metal it was before it was ignited, or calcined.

That this is fact in regard to lead and quicksilver, may be seen from the reduction of these calces by heat, concentrated light, or any inflammable substance, to their original metal. But the pellicles of finery cinder that fall from the burning iron, in the above experiment, are not an oxyd; no air can be got from them by either heat or acid; nor can they be reduced to a metal by any inflammable substance ignited. Water is a material constituent in most kinds of air; and in their decomposition, water is produced. Fire, gunpowder, and moisture, will be found in the cavity where it was fired;—inflame equal quantities of inflammable and vital air together, and water will be deposited; (said to be equal to the weight of the two airs so inflamed). Exhaust a tall receiver on an air pump, and a shower of vapour will be seen to descend in it. A sudden degree of cold will precipitate water from the air so as to cover the walls, wainscots, floors, and railing of houses, with moisture; so, in like manner, is rain, snow, and hail produced. Breathing in a close carriage covers the glasses with moisture; this is the moisture thrown out of the lungs in the act of breathing, condensed by the cold, on the outside of the windows: so it is in assembly rooms; or where a great number of people are in a close room: in short, thousands of operations, in both nature and art, demonstrate water to be a constituent part of most kinds of air—for in their decomposition water is universally exhibited. Even water itself, without any other ingredient, may be converted into permanent, elastic, and respirable air by means of heat; for fill *a b*, Fig. 19, about two thirds with water, and the rest with quicksilver, then by laying the thumb on the open end *a*, and inverting the tube in the bason of quicksilver *a c*, the water will fill the part *d b*, and the quicksilver the part *a d*. If, then, a candle be placed leisurely to heat

the water in the inclined tube, it will rise in steam at *b*, and depress the quicksilver at *d*; this, for some time, will be nothing but common steam, convertible by cold back into water; but if this water be kept boiling for the space of an hour, a permanent air will be produced.

What then is the atmosphere? A compound of every kind of body capable of a gaseous state by means of heat or fermentation; a receptacle of aqueous vapours; mineral exhalations; of steams, arising from the perspiration of whatever enjoys animal or vegetable life, and of their putrescence when deprived of it; of acids and oils separated from fuel in combustion; a chaos of the fine particles of every body with which the air and light have contact; a solution of terrestrial matter in solar light, or fire; for the sun seems to have been the original parent of our atmosphere by means of his heat; so that, though we say that atmospheric air consists of oxygen and azote in certain proportions, it cannot be proved to be strictly true; for certainly there is fixed air (or carbonic acid air), inflammable air (or hydrogenous air), and many others; as well as steams and exhalations from innumerable substances that unite with the general mass of the atmosphere; all kept in a fluid state by their union with fire or light. It may be said, that the atmosphere is half its time left without light: yes; but the effects of a fire in a room are long felt after the fire is extinct; and cold increases from the setting of the sun till his rising. Latent fire is put into action, and made sensible, by means of active fire. I hold a poker before the fire; it grows hot; not by the fire or heat it imbibes, but by the latent fire it already possessed being put into action by the repulsive power of the fire before which I held it. I lay fuel upon a fire; it will not burn till it is heated; that is,

till its inherent, its natural fire, is put in motion by the repulsive power of external heat. I rub a piece of phosphorus between the folds of brown paper before it will ignite; because the friction puts its latent or fixed fire into motion, and assists its disposition to unite with the air, to which it has the most natural affinity, and thence to break out into flame: even a candle will not light till its snuff be heated. Light, therefore, considered as diluted fire, lies dormant in darkness (without losing much of its repulsive property), for night air is not found to be much more dense than day air, because of the short absence of the sun, which by his stream of light soon puts the stagnant fluid into motion, and produces all the effects of vision, reflection, refraction, heat, &c. in the day. The repulsive power of light, and its identity to that of fire, I hope is sufficiently proved in the Optical Lecture, as well as that the fluidity of the air is owing to its repulsive power; and though light may have its power of affecting the optic nerve suspended in the absence of a luminous body, it still exists even in darkness, and wants only a luminous body to put it in motion, and make it sensible light.

That the earth is the natural parent of the atmosphere is evident from the immense number of animal, vegetable, and mineral substances which produce air by means of heat, or by ſtronger affinities. I bruise the mineral substance called manganese, and put it in a stone or iron retort *a*, Fig. 20, which being flat, may be thrust in between the bars of a kitchen fire; its mouth *b* is ground to fit the metal pipe *c*, and *c* is united to the close but flexible pipe of leather *d*; to *d* is joined the long metal pipe *e*, which may either come over the top or through the water-bath or vessel *g*, into *b*, the bottle that is to receive the air. When a brisk fire is

made round the retort *a*, a little common air in the interstices of the manganese will come over first, and may be suffered to escape; but, after fifteen or twenty discharges from the pipe *e* through the water in *g*, the bottle *h* full of water may be inverted on the end of the pipe *e*, when the oxygen gas, or dephlogisticated air, will rise into it with great rapidity, and soon expel all the water that was in it; this bottle removed, another and another may supply its place; so that ten or twelve quarts of pure vital air may be expelled from one pint of bruised manganese. Was not this air, in a ſolid ſtate, a part of the manganese before it was exposed to fire? Did fire any thing more to it than repulse it from the bases with which it was united, and unite with it itself? and by that union keep it in a permanent gaseous ſtate? Does not the sun by his heat perform the same thing every moment, and on every part of the calciform parts of the earth exposed to his heat? and is not a considerable portion of the earth's surface (and that to a considerable depth) in a calciform ſtate? Scarcely can we lay hold of an handful of earth, but, by applying an acid to it, with a due portion of heat, vital air may be produced. It is true that chalk, limestone, marble, shells of fishes, and all calcareous earths, produce, in their union with fire, an air poisonous to the lungs of animals that breathe. It has been called fixed air, aerial acid, and now carbonic acid gas, as being supposed to be derived from charcoal. Why chalk, the dung of animals, &c. should be called charcoal, is beyond my comprehension. That charcoal, heated in a retort, does produce the same sort of air is certain; so do vegetables in the vinous state of fermentation, and many other matters that have no other quality in common with charcoal.

Thus nitre, acted upon by either solar or culinary heat, produces vital air. This salt is spread more or less over the surface of the

whole habitable earth, and is produced from a mixture of animal and vegetable earths and juices. The process of nature in producing pure air from this salt is successfully imitated by distillation, *i. e.* by the same process that was used with manganese.

The effect of solar heat on chalk, limestone, and other calcareous earths, is *fixed air*, or carbonic acid air. This effect may be smelt in chalk pits on an hot day; and tasted, after agitating this air in a bottle half filled with water; the water acquiring in a degree the acidulous taste of Pyrmont water. The carbonic air that forms a thin stratum on the floor of the Grotto del Cano (that suffocates dogs and other low animals immersed in it), is another instance of the natural production of this part of our atmosphere. But as this air is specifically heavier than the general mass, it separates from it in the night, or when the air is quiet and free from wind, and falling down on the earth, becomes elaborated into the food of plants, being a principal ingredient in the causes of their growth. Hence arises the fertilizing quality of lime, of shells, and marles; and the rapid growth of plants, whose roots are treated with fixed air. That fixed air is a constituent part of vegetables is evident from the quantity they throw out when put into a state of fermentation; so that, like putrefaction, which disorganizes some bodies to feed others, fixed air is discharged from the decomposing body, and becomes the food and part of the substance of the growing plant. If wood be charred in close vessels, so that the air cannot escape, the air becomes fixed in the charcoal; but if this charcoal be distilled in the apparatus, Fig. 20. that fixed air becomes volatilized by the heat, and comes over an aerial acid, a carbonic, or fixed air; the coal delivering back to the atmosphere the very particles of air it imbibed when a living plant. It is true, that solar heat is not equal to that which is necessary to

produce those airs in the laboratory; but when we take into the account the continued action of the sun, and see the steams and exhalations which he enables the air to extract from the earth, we may say, that our boasted effects produced in the laboratory, are but the humble imitations of what that great chemist, the Sun, has been producing every day since the beginning of time!

Besides this heavy air which separates from, and sinks to the bottom of, the atmosphere, there is also a part that is lighter than the rest, and no doubt forms a stratum in the upper regions of the atmosphere; this, as well as the heavy air, will be mixed with the general mass by the winds, and other commotions in the air, and may be brought within the sphere of attraction of bodies to which it has an affinity, and unite with them. This has been called phlogiston, inflammable air, and now hydrogen gas, as being supposed to be one of the ingredients that compose water. It is produced by nature in various decompositions, both animal, vegetable, and mineral. In the animal kingdom, when that subtil chemist, putrefaction, takes in pieces an organized body, sending earth to earth, water to water, air to air, &c. the inflammable principle of the body is also let loose; and if it meets with a warm still air will often ignite spontaneously, as may be seen in hot climates over a recent shallow grave, on a still evening, like a pillar of ignited particles.

The air which swells the bodies of dead animals, is a compound of inflammable and fixt air, which, when discharged, each returns to its proper function; fixt air to the earth, and the roots of plants, whilst the inflammable part ascends to the upper regions, often forming meteors, falling stars; and sometimes in the very act of discharge from rotting animal and vegetable substances, ignites in

the character of Will-o'-th'-Wisp. In muddy ponds, near great towns, inflammable air may be procured in great abundance, by filling a bell-glass in the pond with water, and inverting it in the water; if then the mud be stirred with a stick beneath it, bubbles of inflammable air will rise from the mud, and fill the glass; this air being exposed to a candle, will take fire, and often explode. The living fraxinella throws off so great a portion of this inflammable matter, that the air around it will take fire from a candle, like the air in a coal-pit. Metals decomposing by exposure to air, or water, throw off great quantities of this inflammable matter, losing thereby their metallic splendor, and becoming calces, or oxyds. So iron and zinc, exposed to a violent fire, throw out inflammable air; and if iron filings are exposed in the focus of a burning-glass, they will leap about, and shew that aeriform matter is expelling from them by the heat. We are instructed that metals become calces by imbibing vital air, because many calces are heavier than the metals of which they are made: this is true in calces made by art, but not of those made by nature; for the rust of iron is not so heavy as the iron from whence it became a calx; nor is that of exposed lead, copper, tin, &c.; nor will those calces produce vital air, like the calces of lead, mercury, &c. made by a stream of air passing over them while in a state of fusion; in this process the air is diminished, its purer part disappears, and the rest will neither support animal life, nor flame: no doubt the calx has seized the pure part, by means of a superior affinity; assuming a concrete form, adding weight; and is ready to give back this concrete matter in an aeriform state, when forced by the power of fire, or a still stronger affinity, as has been shewn. May not the particles of this kind of air have a stronger affinity to fire, or light, than any other? by which its particles are pushed to a greater distance from each other than in common air? and thereby derive its great levity, its

elasticity, and inflammability: but alone it extinguishes flame; and will not explode without a mixture of vital or common air: for vital air contains within itself the principle of fire, as well as inflammable air, but holds it with a weaker affinity; hence this fire emerges upon its union with the body in combustion; and by extricating fire from inflammable air with some difficulty, it bursts out with explosion.

Inflammable air (or *hydrogen gas*) is produced in great abundance by means of the apparatus, Fig. 21. *a b c* is an horse-shoe tube of cast-iron, with the ends *a* and *c* made to receive ground stopples; the tube is filled with iron wire, or bits of clean iron, and then thrust in between the bars of a hot fire: the cup and tube *d a*, is luted into the end *a*, and so is the tube of Fig. 21, into the end *c*. The cup *d* is now filled with water, which is prevented from falling into the great tube *a b c* by the conical valve *e*: but this valve can be opened more or less by the screw *s*, so as to let the water drop leisurely into the hot tube *a b c*. Inflammable air (thirteen times lighter than common air) will now come over with violence into the inverted bottle *q*, which must be replaced with dispatch by other bottles filled with water. When the process is over, the tube and the iron within it will be found to have acquired weight; the wire, in particular; which will appear like Ethiop's mineral, or the scales around a blacksmith's anvil.

Mr. Lavoisier having made this experiment the foundation of a new theory in chemistry, it is necessary to observe, that he weighed the tube, the wire, and the water; and he secured the water from evaporation prior to the process: when it was over, he weighed the tube, the wire, and the air produced, and found they had ac-

quired just the same weight which the water had lost. This he considered as analytically decomposing the water, or taking it in pieces, as it were; and in order synthetically to recompose it, or put it together again, he took the air produced, and as much oxygen gas, or vital air, as he supposed might be produced from the oxydated wire and tube, and setting fire to them by an electrical spark in a strong close vessel (exhausted), he found, after the flame had expired, a quantity of water deposited exactly equal in weight to that which was expended in the first experiment. This experiment was contrived and executed with the utmost precision, caution, and address, and with instruments in which neither accuracy nor expence was wanting; yet I confess that the conclusion drawn from it, viz. that water is composed of hydrogen and oxygen gas, is by no means clear to me. In the first place he takes as much oxygen gas as he *supposes* might be produced from the oxyd of the iron and wire to burn with the hydrogen gas: now this is supposition; he did not make the oxygen gas from the individual oxydated iron; but what is more, it is impossible to make it from iron so oxydated, for that I have tried over and over again, as well as many abler chemists. Besides, to weigh air accurately, and particularly air thirteen times lighter than common air, even with the nice and expensive apparatus of Mr. Lavoisier, I think next to impossible. That water has the appearance of being produced by the burning of these two airs, there is no doubt; nay, that its weight may approximate to the weight of the two airs so burnt, is also very probable; for water is detectable in all kinds of air, and doubtless is its heaviest part; therefore, when any air is decomposed, water is produced. It is well known, that a mixture of highly concentrated sulphuric acid (vitriolic acid) and water, will produce a heat greater than that of boiling water; for if into equal quantities of

these a thin glass vessel be put filled with water, the water will soon boil. Now when inflammable air is produced from iron filings and diluted vitriolic acid in the common way, this heat is produced: for if that heat be suffered to cool before the iron is put to the mixture, the effervescence will be very weak, shewing how necessary fire is in the production of inflammable air. Into the strong bottle *a*, Fig. 22, we put a quantity of nails, iron filings, or bits of clean iron, and just cover them with water; if then, about one-fourth of the quantity of water of strong vitriolic acid be poured into the bottle, a violent ebullition will begin: the crane tube *b* (having one end a ground stopple for the bottle *a*) is now fixed in the bottle *a*, and its other end under the bottle *c* (full of water, and inverted in the bason of water *d*), bubbles of inflammable air now rise rapidly to the top of the bottle *c* and displace the water, soon filling the bottle. If the thumb be then placed on the mouth of the bottle, while under water, the bottle may be taken out; and if its mouth be held to a candle, a small explosion will take place there: if then it be stopt, and again addressed to the candle a second, a third, and even a dozen explosions will succeed one another; for the air will not inflame but in contact, or in mixture with common air, so the explosions take place only at the mouth of the bottle. But if a bottle be only half filled with inflammable air, and the other half with common air, it will explode all at once, and moisture will be found deposited in the bottle. But to make this air an ingredient in aerial gunpowder, it must be mixed with an equal quantity of oxygen gas (vital air), in a strong bottle; otherwise, when held to the candle, the explosion and expansion are so great, as to shiver a weak bottle to pieces. Pistols are often charged with these two airs, in the pneumatic tub; and sometimes, when common air is used, by placing the pistol over the effervescent bottle, as Fig. 23.

The pistol *a* being naturally full of common air has its mouth placed loose on that of the bottle; but the inflammable air being lighter will mount up to the top of the pistol, and displace an equal quantity of the common air: if now a cork be put in the mouth of the pistol, and the knob *c* approach the excited conductor of an electrical machine, the cork will be discharged with the velocity of a musket ball, and with a loud report: for the knob is screwed on the end of a wire *c d*; which wire being cemented in the inside of a thick tube of glass, it becomes insulated from the metal of which the pistol is formed; this tube is also cemented into the neck of the pistol; so that when the knob approaches the electrical machine, a spark takes place at *d*, which sets fire to the inflammable and common air in the pistol, and discharges the cork. Many other amusing experiments are made by inflammable air, as may be seen in the lecture on electricity. But the intention here is to endeavour to account for the appearance of water on the inflammation of these two airs. The sulphuric acid (vitriolic acid) will not attack iron alone, it must be highly diluted with water, before inflammable air will be discharged from the iron (for still I do conceive that it is the iron which produces the greatest part of this air): water instantly seizes the acid, which becomes decomposed, and its latent fire is let loose, to the air or other surrounding bodies;—and the water and acid are diminished in their volume, that is, they form a penetration with each other, that makes their sum less than their two parts separate, occasioned by the loss of heat.—It is also proved, that when this gas is let through water in the vessels *c* and *d* Fig. 22 that the same quantity weighs one-eight more than when it is let through these vessels filled with quicksilver; proving its strong affinity to water, and that it holds it in solution. —Now as this experiment is generally made through water; and

as a quantity of water rises with the gas in steam, from the excessive heat produced by the water and acid, as above, is it not more than probable, that, in decomposing this air by firing it, the water in solution, and that in the character of steam, become disengaged, and return to their elementary state of simple water, and even to weigh as much as the air, when a pint of it, so mixed, weighs no more than $1\frac{2}{3}$ grain? With the most profound respect for the valuable names I differ from, I do think water an element, notwithstanding its apparent composition and decomposition. Is it not the general cement of all other matters? existing (though without the character of water) in salts, crystals, animals, plants, &c. and in this kind of combination giving hardness and transparency to bodies? and uniting the particles of stones, plaisters, lutes, &c? Is there any substance in nature in which we do not find it combined more or less? From even metals it can be expelled visibly by heat. It is united with all acids whether in a liquid or saline form, and, therefore, in the decomposition of bodies, water is universally disengaged. If then, as has been proved by experiment, Fig. 19, water may be converted into a permanent elastic gas by fire; and that every substance in nature is also capable of producing air when duly penetrated with caloric (fire); Is it natural to suppose that a fluid which constitutes more than half our globe should be formed by the slow process of burning oxygen and hydrogen gas together? Is it not more consistent with the wisdom and frugality of nature, that these gasses should be formed from water? But these gasses cannot be formed from water alone; other substances, containing inflammable matter, must be united with water in the process, or no hydrogen gas will be produced. With a blunt steel point, a hole may be beat through at *a* in the bottle *c*, Fig. 24. If then the wire *d* and its knob be cemented in that hole, the bottle may

be filled with water, and inverted in the bason of water *g*. Take a wire, with a knob at each end *y*, and bend it so that one knob may be half an inch from the knob already in the bottle; if the knob *y* be made to communicate with the outside of a Leyden jar, and the knob *d*, with its inside, discharges of electricity through the water will generate inflammable air; *which can be only an union of electric fire and water:* proving, that if fire can be forced into union with water, the compound will be inflammable air. Iron contains inflammable matter, and will burn like a stick in vital air. Both in the experiment, Fig. 21, and that, Fig. 22, the iron lost its inflammable principle, and became rust, or a finery cinder; it is, therefore, more than suppositious that the iron supplied the inflammable principle to the gas, and the electricity to the water. This inflammable principle has been called the phlogiston of metals; I take the liberty of calling it *light*, in the first instance, and *fire* in the second, when it becomes condensed, incorporated with, and a constituent part of a body. That light forms the greatest part of all plants, I hope will be sufficiently proved in the Optical Lecture; that wood in charring has this light concentrated into fixt fire; and that (according to Bergman, ninety-nine parts in 100 of charcoal is fixt fire, or phlogiston) the ore of iron must be fluxed in a furnace with charcoal before it becomes a metal. Does not the metal then derive its splendor, its texture, its strength, &c. from the inflammable part of the charcoal? and is it not ready to give back the inflammable principle in its original state of light when ignited in vital air? and also when an acid tears it from its basis in the formation of inflammable air? This air still holds in solution the fixed fire of the metal, which may be exhibited in its original state of light when ignited in vital air, and be thence thrown back into the general mass of light. This doctrine is further corroborated by reducing

the calces of metals to their metallic state in inflammable air. Put a little minium, or calx of lead, in the crucible *a*, Fig. 25, and place it on a stand under and near the top of the bell-glass, and place both in a bason of quicksilver, with the syphon *s t*: the mouth applied at *t* may draw out the air from the bell-glass, and the quicksilver will rise up to the crucible by the pressure of the atmosphere on that in the bason. If then the bottle and crane, *a b*, of Fig. 22, be replenished with iron filings, and diluted vitriolic acid, and the crane be put under the bell-glass, as in Fig. 22, the quicksilver will soon fall to the level *o o*, and the space, *a*, will be filled nearly with inflammable air. The apparatus being exposed to a hot sun, and the large lens *n r* held before it, so that its focus may heat the minium; the air in the bell-glass will soon begin to diminish, and the minium to change from a red to a yellowish colour: as the air keeps diminishing, the metal revives; and if there be air enough, the calx will soon become splendid lead. What has made it so? Doubtless its union with the inflammable air; and for the same reason that charcoal will revive a calx, or an ore, into a metal. It is true that solar light, concentrated on a calx, by a large burning lens, will restore the calx to its metallic state, and, no doubt, it assisted in the last experiment; but this is another proof *that light is the true essence of all inflammability.*

From the great inflammability of this kind of air, there is reason to believe it is more saturated with latent fire than any other part of the atmosphere; that its particles are repulsed to a greater distance; so that with as great elasticity as common air, it possesses the singular property of being ten or twelve times lighter, bulk for bulk. Upon its first discovery, I thought that if a very light bag could be devised that would retain it, the bag and air together would be buoyed up in the atmosphere, like a cork in

water; my first trial was to fill soap bubbles with it; they succeeded, and were the first air balloons ever made. This amusing experiment is easily made by tying the mouth of a bladder to a stop-cock *c*, Fig. 26, and screwing this on another fixed on the top of a bell receiver *a*. This receiver is filled with inflammable air, as before directed; if then the two stop-cocks be opened, and the receiver *a* pressed down into the water *b*, the air will be forced up into the bladder *d*, and fill it: the stop-cocks being shut, the bladder may be unscrewed from the receiver *a*, and a short tobacco-pipe, with a little thread wrapt round its end, may be screwed into the stop-cock of the bladder, as Fig. 27. When the pipe head is immersed in soap-suds, and the bladder a little squeezed, bubbles may be thrown from the pipe, that, in still air, will rise out of sight. This effect depends entirely on hydrostatic principles, viz. that a body heavier than its bulk of a fluid, will sink in that fluid; for the pillar of which that body is a part, being heavier than the pillars of the fluid that surround it, the body must sink by its superior gravity. But a body that is lighter than its bulk of the fluid in which it is immersed, will rise up and float on the surface, and part of it will rise above the surface. So a body being of the same weight in a homogeneous fluid, as its bulk of that fluid, will float promiscuously at any depth in it. Air balloons that could float two or three men in the atmosphere, rose on this principle. Gores of silk were sewed together, so as to form a pear-like bag (which was made tolerably air-tight by a varnish made of India rubber), twenty-seven feet in its greatest diameter. A net of small cords is spread over its top, terminating a little below the bottom in a small basket, in which the aeronauts were suspended. A tube of the same materials as the balloon, hung from its bottom to receive the air, and also to let it out when the balloon began to swell in the upper regions of the atmosphere. The air was produced from

zinc and iron, by diluted vitriolic acid, in leaden retorts (because that acid will not dissolve lead), and suspended between two long perpendicular poles, the balloon was thus filled with inflammable air. When empty, the weight of the balloon, and two adventurers, was 604lbs.; but 20lb. more being hung to the balloon when full, kept it in equilibrio with the atmosphere, so that its power of ascent, added to its weight, made 624lbs, the weight of an equal bulk of atmospheric air, to that of the balloon, the two aeronauts, baskets, &c. On its ascent, the barometer stood at 30°, and soon fell to 27°, by which it was calculated that the balloon was about 600 yards above the earth; by throwing out ballast occasionally as the balloon descended by loss of air, it was kept about that height an hour and three quarters, on a voyage of twenty-seven miles.

Additional fire, added to that which the atmosphere naturally contains, repulses its particles to such a distance, as to make the air, so heated, rise in the atmosphere like a cork in water: hence smoke is carried up by its temporary connection with heated air; and its gross and sooty part is precipitated back to the earth when that air becomes cooled by mixing with common air. This dictated the idea of a Montgolfier, or a fire balloon, Fig. 28. A light paper bag, with its mouth downward, will rise in the air, if a spunge, *a*, soaked in spirit of wine, be supported a little above the mouth and set on fire. It is neceſſary, first, to inflate the bag a little by burning ſlips of paper in it; the spunge will then burn without danger of firing the balloon; in which case it will often rise above the clouds. Machines of this kind have been made of 60 feet in height, and 43 in diameter, and capable of lifting five hundred weight from the ground. Small balloons may be made by ſticking gores of ſilk paper together with gum water. For

these machines to have the power of ascending with the weight of two or three men, their volume must be so large, that their direction will always be subject to the wind. But obeying the wind, they have ascended over camps and besieged towns, with a cord so attached to them that they could be drawn back to the place from whence they were launched.

Various other airs have been fabricated by art, possessing singular properties.

Nitrous Air,

Or the test air, is formed of the fire of any metal, united with the nitrous acid. Copper is most commonly used; being put in small slips in a bottle, *a*, Fig. 29. This bottle is then nearly filled with diluted nitrous acid; and the crane-stopple, *c*, is fixed in it, and its end put under the shelf, *d*, which has holes in it (as *z*) to let up the gas. This shelf is just covered with water; and the cistern in which it is fixed is deep enough to suffer jars and bottles to become inverted under water. The jar, *e*, therefore, being filled with water in the cistern, and inverted on the shelf, *d*, it receives the gas, and the water in it falls down into the cistern.

This criterion air unites suddenly with vital air, with which it forms nitrous acid, and which appears in a brown cloud; this nitrous acid is suddenly imbibed by water, and in proportion to the quantity of vital air contained in the mixture. Pure vital air will imbibe fix times its bulk of nitrous air, before water will cease to imbibe the two airs in the character of nitrous acid. And common air will take up a little more than half its bulk of nitrous air without its bulk being increased.

These experiments are thus made. A small glass cylinder, Fig. 30, is cemented into the brass socket, *c*, in which is a flider, *a*, that will shut close over the mouth of the glass; this vessel is called a meafure. This measure being filled with water, and inverted in the pneumatic cistern, Fig. 29, and having the tunnel, *m*, put under it, is easily filled with any gas or air under water: the slider is then pushed in, and the air in the mouth of the measure turned out, and so the gas or air is transferred into the long tube, Fig. 31, already inverted in the cistern and full of water. The gas so transferred will rise up to the top of the tube, and expelling its bulk of water will occupy the space, *x*, *y*. If this be vital air, then may fix measures of nitrous gas be added to it, and, after all, the air will only occupy the space, *x*, *y*. If two measures of air be taken from the very close and populous parts of a great city, and put into the tall tube, *z*, *x* (called an eudiometer), and one measure of the test or nitrous air be put to them, a brown effervescence will take place, and the three measures will instantly only occupy the place of two; displacing the water from *x* to *r*. The air from fuch places may be considered as the ftandard of impurity: and air from any place may be easily taken, and easily conveyed to the pneumatic cistern, by filling a bottle with water, and pouring the water out in the place where the air is to be taken from; the bottle then becomes filled with the air of that place, and, well corked, may be conveyed to any distance. By these two extremes, the quantity of vital air, in any common air, may be easily estimated: for as oxygen gas, or vital air, absorbed fix times its bulk of nitrous air, and only occupied its original space, *x*, *y*; and as two measures of impure air only absorbed half their bulk of the trial air, twice fix will be a scale expressive of the degrees of purity between *r* and *x*; i. e. if I bring a bottle of country air to the test, and find after two measures of it have absorbed one of the criterion air, that the

water in the tube will rise above *r*, perhaps to *s*, two twelfths of the scale *r*, *x*; then should we pronounce *that* air to contain one fixth more oxygen, or vital air, in it, than an equal quantity of the city air.

The first dozen of bubbles that come over when the nitrous air is distilling, should be thrown away; the rest will be very good, and will be a tolerable test of the proportion of vital air contained in any air. For it has been found that the duration of life, in animals confined in closed vessels, keeps time nearly with this test; *i. e.* two birds, or two mice, being confined in two bell-glasses of the same size, one full of pure vital air, and the other of such country air as above described, which would only absorb one sixth as much trial air as the pure air; in this case, if the animal in the country air lived an hour; that in the oxygen gas would live six hours, &c. The reason is plain, if we recur to what has been said respecting breathing; for it is proved that the air taken into the lungs undergoes a decomposition, the purer part being absorbed by the blood in the lungs; the latent heat is let loose and carried by the blood in an active and sensible state through the body, thereby giving it animal heat; and the impure, or azotic part, thrown out at the mouth and nostrils. Now that air which contains *most* of those vital principles, will supply life the longest. For the blood nourishing the body as it travels through the arteries, returns by the veins to the heart and lungs, a thick and dark coloured fluid, and is propelled up to the lungs, to be replenished with heat and vital air; it then returns into the circulation thin and florid, and capable of making its way through the finest ramifications of the body. Hence, to breathe air, in want of its natural quantity of oxygen, is to send the blood unrecruited from the lungs into the circulation; thick, and incapable of being forced by the

heart through the fine vessels; these swelling, form pressures upon the neighbouring nerves, that by degrees bring on spasms, convulsions, and death. Thus died the people in the hole at Calcutta; two men in a diver's bell, in the bay of Dublin; and so would all land animals, obliged to breathe the same air over and over again. One bird, therefore, having in its air six times as much oxygen as the other, would necessarily live six times as long upon it. It is unnecessary here to expatiate upon the necessity of breathing this pabulum as pure as possible; all are sensible of it, all feel its necessity; yet, with double doors and curtains, do we strive to keep it from our apartments as if it were a public enemy. Many disorders to which our forefathers were strangers, date their number and malignancy from this unmanly delicacy! Why are pulmonary complaints so prevalent in large cities? Is it not from the soot, smoke, and putrefactive vapours we breathe? Nature has guarded the lungs, by an outwork of hair at the first pass where the air enters the human frame; there its grosser impurities are stopt; after it has entered the nostrils, a crooked road to the mouth is lined with a gluey mucus, that arrests smaller particles: but should any of those pass these guards, there is a centinel at the gate of the lungs, of so irritable a nature, that if an atom touches him, he throws the whole frame into convulsion and resistance! What has nature done all this for?—Perhaps as a hint to keep mankind from herding together, and corrupting one another in great cities. Some particles, however, will pass this centinel in spite of his vigilance, and form a lodgement in the lungs; and the accumulation will be reinforced, in many, by the irritable particles of snuff. Matter thus acccumulating in the lungs, where it cannot be digested, nature is obliged to throw it out by coughing, and we call the convulsion a cold! But to return—We estimate the respirable goodness of atmospheric, or other airs, by the quantity of

nitrous air which they will dissolve: but this air has other qualities not unworthy of notice; its antiseptic powers are greater than those of fixt air; flesh meat may be preserved sweet in it for several weeks, in the hottest weather.

Water and acid have so strong an affinity, that four ounce measures of water will imbibe near 300 measures of nitrous air.

Nitrous acid entering into nitrous air, exhibits this acid in great variety; being an ingredient in the most wholesome, the most noxious, the most pure and impure of all kinds of airs: for nitre distilled, yields the most salubrious vital air; but nitrous air is noxious, and cannot be breathed.

If a bottle, Fig. 32, be filled three-quarters with common air, and one-fourth with water; and a bladder, filled with nitrous air, be squeezed into it; the air in the bottle will absorb the whole nitrous air, become nitrous acid, and be absorbed by the water.

Air, in which animal substances have lain sometime in a putrid state, has its putrescence washed away by passing through water, and will bear the test of nitrous air. For smell consists of the fine particles of bodies dissolved in fire, which particles may commonly be detached from that menstruum by mixing with water.

It is supposed that there is as much fire, bulk for bulk, in nitrous as in inflammable air.

Nitrous vapour arises from nitrous acid being poured on bismuth: a brown effervescence issues with rapidity from this mixture, which, being conveyed by the bent stopple tube *a*, Fig. 33, can be

conveyed into, and imbibed by, water, and other fluids. So distilled water, when warm, imbibes this vapour, and becomes very pure nitrous acid: and two measures of this water (after impregnation) become three. It also attacks copper more strongly than diluted nitric acid.

The volatility of this vapour in water, so impregnated, is curious: if in an open flat vessel, a person blows upon it, a copious red vapour issues from it; and the green and blue colour of it entirely vanishes.

Nitrous acid diminishes in weight by exposure to the air; vitriolic acid increases in weight. The first by exhaling; the latter by attracting moisture from the air.

The end of the tube *a*, Fig. 33, immersed in vitriolic acid (when the vapour issues from it), turns the acid blue. If water be poured upon it and stirred, heat, and a copious vapour, arise of a striking appearance.

Marine acid, impregnated with nitrous vapour, is a powerful aqua regia, that will dissolve gold without heat; and nitrous ether is made by impregnating spirit of wine with nitrous vapour.

Red lead, stuck by moisture, to the side of a phial, is heated, increased in weight, and turned white, by the admission of nitrous vapour.

The superabundant quantity of fire in nitrous air immediately quits it, on being united with common air; i. e. an equality is restored between them.

Nitrous air diminishes none but respirable air.

The nitrous acid that enters into the copper, when dissolving, is six times as much as enters into the nitrous air produced by the solution.

Nitrous air imbibed by water, is expelled by heat, as well as by freezing: in the latter case it deposits a sediment.

Nitrous air is fatal to plants.

So strong is the attraction of water to the nitrous acid, that it will draw it through a bladder containing nitrous air: what nitrous air remains in a bladder will become respirable; and the water, on which the bladder floated, will become acid.

No air can be procured from concentrated nitrous acid and metals. Water is indispensable, and a constituent part of all airs.

Facts respecting Vital Air.

About one-third of the mass of the atmosphere is understood to be vital, or such air as will support flame and animal life. It may be extracted by heat from nitre, from alum, from precipitate per se, from minium, from manganese, and from lapis calaminaris. It is found in the bladders of sea-weed, and in fresh and salt water. It is produced by green vegetables, and green matter, inverted in vessels of water, exposed to light; for in darkness vegetables so circumstanced give out only the fixt air they originally drew in as

nutrition; but light becoming a constituent part of all vegetables, by the vital affinity they have to it, is elaborated with the air into the constitution of leaves and fruit; and when given out by them, is found to have derived from light the principle of supporting life and flame.

Nitrous acid produces vital air from all metallic, and other earths: heat produces it from green, blue, and white vitriols; and vitriolic acid, from minium, or red lead.

The most refractory ores and metals can be fused by charcoal, burnt in vital air. Iron burns in it with a brilliancy too dazzling for the human eye. It enters into the calces, or oxyds, of metals fused in it, making them heavier than the metals themselves; which oxyds will give out that air again in its original purity, when urged by heat, or the acids. It is only the vital part of any air that is capable of being diminished by means of nitrous air.

Two similar animals, inclosed in two vessels of the same size, one filled with vital, and the other with common, air, will live a length of time in proportion to the purity of those airs, i. e. if in the common air, there be but one-third of it vital air, and the animal inclosed in that air shall live an hour, the animal in the vital air will live three hours, &c.

Facts relating to Inflammable Air.

THIS fingular air consists of fire and water, fixed by an earth. It may be expelled from metals by the heat of a large lens *in vacuo*,

or when confined by quicksilver, without the intervention of water, and may be considered as the nearest approach to elementary fixed fire of any principle in nature.

Diluted vitriolic acid expels this inflammable principle from iron and steel, by seizing the earth of the metal, and forming with it a salt or calx, consisting of the acid of the vitriol, the earth of the metal, and water for crystallization; while the fire of the metal and of the acid becoming active, heats the water into steam, thereby qualifying it to unite with the fire and part of the earth of the metal, in the character of permanent inflammable air. The new doctrine would prove this air, or hydrogen gas, to be produced by *water*. Reasons have already been given for *metals* affording its principal ingredient. That water is a constituent part of it, and all other airs, I hope has been proved; as well as how water is produced by the burning inflammable with other airs.

This air is procured from regulus of antimony by marine acid; from metals by mineral and vegetable acids; but from copper and lead, better by the marine acid. It is also procured by taking the electric spark in oil, in spirit of wine, and in volatile sal ammoniac; if the same sparks be taken in alkaline air, its quantity will be three or four times increased. Animal and vegetable substances yield inflammable air by putrefaction; and it rises spontaneously from the mud of stagnant pools or ditches, where animal and vegetable matters are in a state of putrescence. It is yielded by distillation from vegetable earths, in quantity proportionate to its fertility: oil of turpentine, coals, wood, and all inflammable matters, yield it by distillation.

A few drops of ether in a blown bladder renders that air inflammable; and when common air passes through the flame of the oil of turpentine, it becomes inflammable; see Fig. 34; for if the receiver *e* be exhausted, and the flame of the oil be held to the pipe *a*, when the cock *d* is opened, the air will rush through the flame, and carry along with it a quantity of unconsumed oil, which will render the air in *e* inflammable.

Air pent up in the hollows and crevices of coal mines imbibes inflammation from that fossil. This air, though stagnant, retains its natural elasticity, and, therefore, when the outward air becomes light, by the causes already mentioned, this air will spring from its imprisonment into the mine, more elastic from its acquired fire. Hence the poor miner shall one day take his candle with impunity to the closest recesses of the mine, and the next, the air will take fire like a train of gunpowder, and with hideous explosions blow up both him and the mine. The barometer should, therefore, be consulted before a candle is taken into a mine liable to such baleful damps.

Inflammable air, mixed with fixed air, burns with a blue flame; with nitrous air it burns with a green flame; but when mixed with an equal quantity of vital air in an air-pistol, its explosive power will discharge a bullet almost as forcibly as gunpowder. It is imbibed by water when agitated in it, and may be expelled from it by heat in the same state.

Inflammable air is fatal to animals; and insects become benumbed and paralytic in it. It restores the calces of metals to their metallic state; for if minium be exposed in it under a glass receiver, and the focus of a burning-glass be made to heat the calx,

it will begin to imbibe the air, turn yellow, and in time will drink up the whole, and become real lead.

This air refracts the rays of light more than common air, and is eight or ten times lighter.

On Fixed Air.

THIS wonderful antiseptic has been called aerial acid, fixable air, and now the carbonic acid, as supposed to be derived from charcoal and oxygen. Distilled charcoal certainly produces a gas that has some qualities in common with that expelled from chalk, and other calcareous matters, as well as that produced by vegetable fermentation: but though these have been all called by the general name of fixed air, they each possess peculiar qualities, very different from each other.

Fixed air is heavier than common air; is a weak acid; but capable of holding various salts together, by its affinity to their alkaline bases. It is a constituent part of chalk, marble, limestone, shells, &c. but easily expelled from them by heat, or stronger acids. Hence the vitriolic acid drives out the fixed air from these substances; so does the fire of the limekiln; and leaves the earthy bases caustic, greedy, and rapacious, to tear fixed air from any thing that contains it; dissolving animal and vegetable substances, and rendering acrid salts mild (for salts that are duly saturated with fixed air are said to be mild; and those that have an affinity to fixed air without being possessed of it, are said to be caustic). It is contained in salt of wormwood, in Glauber's salts, in alum, in vitriolated tartar, from all which it can be expelled by

the acids. Nitrous acid expels it from wood and coal ashes; so that a vegetable phœnix may be said to arise from those ashes: for as the nidus of nitre is spread over the earth, and its acid may be made volatile by the heat of the sun, may not this acid attach itself to this residuum of fire, and form with it a fixed air, that (from its superior weight) will fall down to the roots of plants, and become their principal nutrition? and thence have a resurrection from a *caput mortuum* to vegetable and animal life? As an acid, one measure of fixed air will saturate three measures of alkaline air, and will turn red-rose leaves white. It is fatal to vegetables in air and water, but salubrious in earth; not soon fatal to insects. Water impregnated with fixed air kills fishes.

Water has a strong affinity to this air; it imbibes it almost in its passage through it; and thence acquires the acidulous taste, the sparkling appearance, and medical qualities, of the Pyrmont and Spa waters; and when made in the following manner, as exhibited in Fig. 35, may be made much stronger, and in large quantities. *a* is a barrel suspended on the pillars *c* and *d*: in the head of the barrel, *n*, there is a socket of brass or iron, into which the fixed and hollow axle *o* exactly fits; so the barrel turns upon it. The bottle *x* contains the chalk, and diluted vitriol, which may be inserted or replenished through the stopple *p*: *z* is cylindrical bellows, made of varnished leather, very close, and on which the weight *s* may be occasionally laid. When the cock *o* is shut, and the effervescence is going on in the bottle *x*, the bellows will fill. If the barrel *a* be nearly filled with water, the cock *o* be opened, the barrel swiftly turned by the handle *g*, and the weights laid on *z*, to force the fixed air into the barrel, the water in it will become strongly impregnated. By this means any quantity of water may be medicated with small labour and expence; and

when quickly bottled, and well corked, will continue good many months.

There are many methods of impregnating water with fixed air; but without ſtrong agitation the water never becomes ſufficiently saturated.

The antiseptic properties of this air and medicated water are numerous and remarkable. The saline draught is salubrious, by discharging fixed air in the stomach. Sugar, malt, preserved vegetables, &c. boiled, and in a state of fermentation, given to patients in the sea scurvy, have preserved men in health even in a voyage round the world. The medicated water, mixed with tartar, has, in many instances, dissolved the stone in the bladder. Inflammation in the bowels has been cured by a clyster of fixed air. Chilblains, and legs in the first stages of a mortification, have been cured by being inclosed in bladders supplied from bottles containing chalk and diluted vitriolic acid. Fixed air, mixed with inflammable air (hydro carbonate), has been breathed with common air in consumptive cases with great advantage, and has operated as a styptic in the lungs in cases of a ruptured blood vessel; though fixed air alone irritates the lungs, and cannot be breathed. Inflamed nipples have been cured by forcing the air upon the part. So powerfully does it resist putrefaction, that a piece of mutton, hermetically sealed up in fixed air, has preserved its texture and appearance above twenty years. Fixed air extinguishes a candle, and even a train of gunpowder, leading into the grotto del Cano near Naples, was extinguished on entering the part where the heavy fixed air lies. A candle will not burn under the clothes when a person has been for some time warm in bed, nor in common air that has been breathed. To blow through a bent tube of glass, containing a little lime-water,

will revive the limestone; the water turns turbid, and the stone is precipitated. Lime-water is therefore a test of fixed air being a part in any air to which the water is exposed. As both breathing and heat, therefore, expel a quantity of fixt air from the human body, it is restored by a due mixture of animal and vegetable food, which, going into a state of fermentation in the stomach, generates a quantity there; and the moisture of the stomach imbibes, and carries it into circulation. Hence the sea scurvy derives its greatest malignance from the want of vegetables.

On Marine Acid Air.

THIS air is procured by distillation from marine acid; and from common salt and vitriolic acid, through quicksilver. The pond of mercury, through which such experiments are made, is generally in a piece of solid wood, hollowed as Fig. 36. The cavity *a*, in the top of the pond, is the same as *c*, seen in profile. This hollow is filled with quicksilver, and spreads thinly over the space *d d*; so that such receivers as *w* may be filled in the hollow part *c*, and placed inverted on the space *d d*. The bottle *s* being three-fourths filled with table salt, and a hole *n* made in the salt with a pointed stick; if this hole be filled with vitriolic acid, a brisk effervescence will ensue, and marine acid air will rise through its crane stopple *x*, and expel the quicksilver in *w*. A lighted candle held under the bottle *s*, will accelerate the discharge of air. An equal quantity of alkaline air being put to this, both instantly disappear as air; and sal-ammoniac is produced. Water absorbs this air, and the union produces marine acid. This air extinguishes a candle with a blue flame. It dissolves iron, sulphur, and nitre.

It dissolves ice; makes camphor fluid, and blue vitriol green. In short, it is but the marine acid in a state of permanent vapour.

On Alkaline Air.

THIS air is generally expelled by a candle from the bottle *s*, Fig. 36, filled one-fourth with pounded sal-ammoniac, and three-fourths with quicklime mixed: it is, in reality, but volatile alkali in the form of air; mild when mixed with fixt air, but common sal-ammoniac when united with marine acid air.

We have noticed that the electric spark taken in alkaline air, turns it into inflammable air, and increases its quantity three times.

As an alkali, it is absorbed by acid airs in this proportion.

By fluor acid air, twice its quantity.

By vitriolic acid air, ditto.

By marine air, and by fixt air, about an equal quantity.

On Fluor Acid Air.

THIS air is procured by dissolving pounded fluor (Derbyshire spar) in hot vitriolic acid; or by just covering the spar with the acid in the bottle *s*, Fig. 36, and expelling the air, by a candle, through quicksilver into the receiver *w*. This air has the property of dissolving glass, and will etch it like a copper-plate, if the plate, or jar, be first covered with a thin coat of molten bees-wax on both sides, and when cold, engraven with the point of a needle on one

side; so prepared it should be put in the box *a*, Fig. 37. This box is about eighteen inches by sixteen, lined with sheet-lead, having a lid *n*, and a double bottom *x*, to distribute the gas equally among the pieces to be etched, which are placed properly for that purpose within the box. About a wine-glass full of bruised spar is then put in the stone retort *s*, and as much vitriolic acid as will cover the spar. The leaden pipe *r* is then luted upon the neck of the retort, and into the false bottom of the box *a*, of such a length that the wax on the glass, within the box, may be in no danger of melting by the fire *z*. This fire may be very gentle, for a small heat will expel the gas; and the more equally and slowly it flows among the pieces to be etched, the more perfect will be the effect. Cyphers, arms, foliage, landscapes, or writing, will be completely etched by the gas in two or three hours, on furniture, window, or other glass.

The jar *w*, Fig. 36, being filled with fluor acid air, and removed out of the quicksilver into water (by placing a small vessel under its bottom), the water will seize the acid, and absorb the air; while the earth of the spar, and the silicious matter dissolved from the glass, will be precipitated in flakes through the water.

From these details, it is easy to conceive how very various the atmosphere must be, over the different soils and climates of the earth; and how far this variety is capable of being imitated, improved, or contaminated, by the means of art. Those airs capable of being produced by ordinary heat, no doubt are mixed and diffused through the general mass of the atmosphere; and where that heat is greater, and the exterior products of nature more volatile, as in the torrid zone, the variety and changes must be very great

and different to those of the more temperate climates: yet in all the air may be conceived as made up of *the finer particles of terrestrial matter dissolved in solar fire:* and art has instructed us what parts of matter are the most susceptible of becoming atmospheric; viz. water; calces of metals; metals themselves in certain circumstances; volcanos; calcarious earths; acids; alkalis; salts; flowers, and leaves of vegetables; artificial fires; many effects of arts and manufactories; animal and vegetable fermentation, putrefaction, &c.

SECTION II.

On Wind.

A WIND is air in motion; its cause is partial heats and partial colds on the earth and in the atmosphere; for heat rarefying the air, makes it occupy a greater space, and therefore to be bulk for bulk lighter than colder air; and a heavier part of a fluid will always tend towards, mix with, or displace a lighter. Hence a large fire in a room will always cause a buzzing at the key-holes and crevices of the room; for the air over the fire being heated, the pillar of air, of which the chimney is a part, will be lighter than the pillars at a distance, and therefore the heavy air will rush through those obstructions, and produce a wind in miniature: thus fire becomes an useful ventilator, and treats the room with perpetual fresh air.

In going out of a great city in winter, a wind is always *met* in every point of the compass; for the heat of so many fires, people,

and animals, making the air so much hotter than in the neighbourhood, the country air rushes in at the exterior streets, bringing its salubrious qualities along with it; and buoying up the light and contaminated air into the upper regions of the atmosphere, to mix with the general mass.

The more extensive winds owe their origin to the sun; for sandy, loamy earths receive from the sun, and deliver to the air, more heat than water, swampy bogs, woods, or cultivated lands do. Clouds and fogs often obstruct the rays of the sun, and absorbing their heat, reduce them to a latent state. Many substances on the earth's surface having a strong affinity to light, imbibe and render it latent. These causes keep the air in a state of perpetual fluctuation. Besides, as transparent mediums, such as clear air, clear water, clear glass, &c. suffer light to pass through them, they receive little or no heat from solar light; insomuch that the opaque earth, receiving its heat from the sun, imparts it to the contiguous air: and hence the air is warmest near the earth, and grows colder and colder the higher we ascend in it.

The *day* breeze from the sea towards and over the land, and the *night* breeze from the land to the sea, in the torrid zone, are accounted for from these principles. The land heats the air, and the cold sea breeze, pouring on the land, buoys up the heated air into the upper part of the atmosphere. Let *a*, Fig. 38, represent an island in the torrid zone, with the winds blowing upon it from the sea, in the direction of the surrounding darts: those winds meeting in the centre of the island at *a*, in opposite directions, will necessarily so accumulate at *a*, as to rise above the common level of the neighbouring part of the atmosphere. This will continue while the sun is up; but on his setting, the cause ceasing,

this protuberance will naturally descend to the level, and pressing out from the land, will cause the night breeze, which always sets from the land upon the sea.

That part of the coaſt of Africa within the torrid zone has (like many others so situated) its day and night breeze, which reaches a considerable way from the shore (see Fig. 39); but the sea breeze being from the west, as *a*, *a*, *a*, while the trade winds blow from the east, as *c*, *c*, *c*, a chasm takes place between them, *x*, *x*, *x*, where the air becomes so rarefied, and, of course, so disposed to let go the water dissolved in it, that this intermedium becomes liable to perpetual calms, rain, and lightning. Irregularities in this intermedium cause the harmatan, a foggy, hot, destructive wind, blowing from the interior part of Africa towards the sea, three or four times in a season, and continuing sometimes several days. For when hurricanes take place in the West-Indies, or extraordinary rarefactions or heats in South America, the trade wind will increase, to restore an equilibrium, and draw the intermedium *x*, *x*, *x*, Fig. 39, more out to sea, or to the westward: this will render the sea breeze *a*, *a*, *a*, tame and weak upon the African shore, and the interior air will flow towards that shore, to preserve a level.

The *trade winds* blow from the east towards the west, for thirty degrees on each side of the equator, across the Atlantic and Pacific Oceans; inclining a little towards the N.W. when the sun is near the tropic of Cancer, and towards the S.W. when the sun is on, or near, the tropic of Capricorn. Thus following the sun, it is evident the sun is the cause; for though perfectly transparent mediums do not receive heat from solar light, the sea is seldom in that state, or even the air; and, therefore, both will be warmed by the sun in his

passage from east to west; not only on the parallel over which he passes, but a considerable distance to the north and south of it; so that the colder air following the warmer, will make a continual current from east towards the west, over the torrid parts of the Atlantic and Pacific Oceans.

Another hypothesis respecting the trade wind is, that, as the air is very thin, or in a greatly rarefied state, by the heat of the sun, in the torrid zone, the earth, turning on its axis from west to east, will leave this light air behind; so that, in respect to the earth's surface, this air must seem to move the contrary way, or from east to west. But certainly, in the course of a short time after the earth began its diurnal motion (as the air is held fast to the earth by the power of its attraction), this air would acquire the same motion as the earth, and then they must move together.

The *sirocco* is a south wind blowing over the sandy deserts of Barbary and Tripoli, and over the Mediterranean. Those sands receive such a degree of heat from the sun, and impart so much of it to the air, as to qualify that air to take up more water in solution than almost any other; hence the surface of the Mediterranean is lowered, and occasions a perpetual current, or influx, at the Straits of Gibraltar; and the hot air becomes so loaded with vapour, by the time it arrives in Italy and Greece, as to be suffocating, oppressive, and almost intolerable to the inhabitants of those countries. Winds blowing from the sea are always moist, bringing, like the sirocco, copious exhalations with them: but winds from a continent are always dry; warm in summer, and cold in winter.

We often see one tier of clouds moving one way, and another tier moving under them, in a contrary direction. A sudden rarefac-

tion in any place will cause the neighbouring cold and heavy air to rush into that place with such rapidity, as to displace, or drive up, the hot air without cooling it: but that rapidity will occasion a rarity behind it, to which the light displaced air will have a natural tendency, to restore an equilibrium, and two currents of air will be then seen moving in contrary directions. This effect may be seen in an hot room, by opening a door into a cold one; for if a candle be held near the top of the door, the flame will be forced out of the hot room into the cold one; but if placed at the bottom of the door, the flame will be forced into the hot room. Heated air always forms a stratum at the ceiling of a room; which, by its greater elasticity, presses out at the top of the door; while the heavy cold air presses in at the bottom to restore the balance. Hence the superior wholesomeness of breathing in high, rather than low, rooms: for when we inspire or *draw in* the air, it flows radiantly from the general mass to the mouth and nostrils in the direction of the darts, as *a*, Fig. 40: but when we expire, or eject the air *from* the mouth and nostrils, the heat it has acquired in the lungs makes it lighter than the air into which it is ejected, so that it is buoyed up into the upper part of the room, out of the way of being breathed again, as the darts issue from *d*.

The *monsoons* are periodical winds affecting the ocean to the southward of Arabia, Persia, India, &c. which countries are subject to excessive heats, when the sun is north of the line, and nearly vertical to them; the winds, therefore, set from the south-west along the east coast of Africa, and up the Bay of Bengal, from the month of April to the latter end of September, obeying that influence. But from October to April, when the sun passes over the meridians of the above places, and shines only on a vast sea, without land to receive his heat, and impart it to the air, that air will

be heavier and colder than the air over Borneo, Java, New Holland, and the Molucca Islands; and, therefore, will flow towards those islands, making a monsoon from the north-west towards the south-east, south of Cape Comorin; and from the north-east to the south-west in the Bay of Bengal, and along the east coast of Arabia and Africa; because the heated parts of Africa, over which the sun passes, and the cold occasioned by the snows on the mountains to the north of India, form such a disparity, that the colder and heavier air rushes towards the warmer and lighter, according to the bearings of those countries, viz. from the north-east to the south-west.

The force of wind is nearly as the square of the velocity, i. e. if on a square board, exposed to a wind, there be a pressure of one pound, if another wind has double the velocity, it will press the board with a force equal to four pounds, &c. Or if a body moving through still air be resisted with a force equal to one pound, if that body move twice as fast, it will be four times as much resisted, &c. Wind, therefore, that travels

1.47	feet in one second of time, is hardly perceptible.
2.93	just perceptible.
4.4	
5.87	gentle pleasant wind.
7.33	
14.67	pleasant brisk gale.
22.	
29.34	very brisk.
36.67	
44.	high wind.
51.34	
58.68	very high.
66.	
73.35	a storm, or tempest.
88.	a great storm.
117.36	an hurricane.

Bodies falling through the air are accelerated in their descent, till the resistance of the air becomes equal to the momentum, or moving force of the body, and then its motion will increase no longer, but it will move on with an equal velocity. For so much does the resistance of the air retard the motion of bodies, moving through it with considerable velocity, that cannon balls, which can only be projected two or three miles, by the power of gunpowder, would fly twenty or thirty in vacuo. By the motion of a cannon ball, the air becomes greatly compressed before it, and rarefied behind it, insomuch, that a mist may be seen preceding the ball.

The *air-gun* derives its power from the elastic force of compressed air. A ball, *a*, of cast-steel, Fig. 41, having a conical valve that opens inward, and which is kept close shut by the spiral wire-spring *c*, air-tight, is screwed at *n* upon the forcing syringe *s*: this syringe has a solid piston *r*, which can be drawn below the hole *z*, by placing the feet on the cross-bar *m*, and pulling by the two handles *y y*: the air will then fill the syringe through the hole *z*. If then the piston be forced to the top of the syringe, it will drive the air up before it into the ball *a*, which the valve *c* will keep there. These strokes repeated twenty or thirty times, will make the air within the ball ten or twelve times as dense as the common air, and to have the force of gunpowder. The ball now taken from the syringe, and screwed under the gun, Fig. 42, will discharge twenty balls successively; for a pin *o* goes through the barrel of the gun, and terminates on the conical valve abovementioned; and the lock of the gun being cocked by the hook *s*, is discharged upon the pin *o*, by pulling at the trigger: the pin pushes open the conical valve, and lets out a small portion of air, but enough to force a ball through an inch board at thirty yards distance. This may be repeated

twenty times with the same charge, and almost with the same force.

The *magazine wind-gun* is still a more formidable instrument. It contains a magazine of balls, shut up in the serpentine tube *a*, Fig. 43. This tube has a continuation through the cylinder *c c*; which cylinder goes through and across the barrel of the gun, the end of which can only be seen in the drawing. This cylinder is of solid brass, and can be turned by the hammer *m*, so as to coincide with the magazine; and if the gun be held perpendicularly, the ball *s* will fall into the cavity *o*, where it will be stopt by two small and slender springs seen at *o*. If now the pan be opened, the hammer will be in the same position as in the drawing, and the ball *z* will be in the barrel of the gun, ready to be discharged. This gun has its charging syringe in its butt; *k* is its piston; this being drawn below the hole *u*, the syringe will become filled with air, which, by pushing the gun downwards, will be forced through the valve *b* into the outward barrel of the gun, A A, which is to hold the condensed air: twenty or thirty strokes will charge the gun, and qualify it to discharge the magazine of balls one after another, as fast as the gun can be cocked, and the pan opened. The communication between the inner and the outer barrel is made by the valve *x*, which is conical, and pressed down by the long spring *g*, so as to keep the gun ready charged for several months. The cock of the gun is united with the piece *e*; which, when pulled back, or cocked, presses down the strong spring *q*, and the catch *r* keeps it in that position, till the trigger *t* disengages it; the lever *v* being, by this means, suddenly struck against the pin that is fastened to the valve *x*, opens it temporarily, and a portion of the condensed air rushes out behind the ball *z*, and discharges it with the force of gunpowder.

By these devices may twelve balls be discharged in succession in as many seconds.

SECTION III.

On Sound.

ALL elastic solids, or fluids, are conductors of sound. The air is one of the most elastic fluids in nature; and, therefore, pervading all places in and upon the earth, it is the most proper medium for conveying auricular intelligence from one creature to another. As fire is a constituent principle in most parts of solid and fluid nature, particularly in those parts susceptible of sound and vibration—and as those bodies that shew the least signs of possessing fire, suffer sounds to pass through them with the most difficulty, as marble, chalk, and other incombustible substances, it is natural to conclude, that fire is the universal cause of the elasticity in all vibrating, or sonorous bodies. If my hand moves swiftly through the air, the air will be driven into a condensed state before my hand, and into a rarefied state behind it; but it will make no sound, and soon restore itself to an equality: the motion of a musical string does the same; it condenses the air before the stroke, and rarefies it behind; but so swiftly do the impulses succeed one another, that the air is forced into successive waves that emanate from the string globularly, and travel at the rate of 1142 feet in one second of time. This is easily estimated by seeing and hearing a gun fired in the night, at 1142 feet distance, when

the light would be seen one second sooner than the report would be heard. These waves from a string, or a bell, may be better understood from Fig. 44, where the string vibrates from *a*, &c. When any obstruction meets these waves, they rebound back and produce echo; sometimes perpendicularly, and sometimes obliquely: when the waves strike inclined upon a reflecting surface, then may the echo be heard, and not the original sound, as Fig. 45; where the direction of the wave *a c* being against the oblique wall *d*, the sound will be reflected to an ear situated at *m*; and if a hill should lie between the bell at *a*, and the ear at *m*, then will the echo be heard at *m*, and not the original sound of the bell. If the head *r*, stands opposite to the rock *s*, and repeats 1, 2, 3, 4, 5, 6; and the word six gets out of its mouth, before the word one returns to its ear, as in the Fig. 46, it will hear the whole six syllables distinctly repeated. But if it be too near the rock, the word one will return before the word six leaves the mouth, and then the echo will be confused: if the distance is sufficiently increased, not only six, but even twelve, syllables, will be repeated by the echo.

The remarkable echo in the dome of St. Paul's church, depends on the same principles. If an ear be placed diametrically opposite to a mouth (in what is called the Whispering Gallery). though many yards distant, the smallest whisper will be distinctly heard. Fig. 47. The natural, or rectilinear sound will pass across the dome from *a* to *b*. The waves that pass from *a* to *d*, impinging upon *d*, will, according to the angle of incidence and reflection (see Optics), be reflected to the ear at *b*: and the waves that strike the dome at *c* will be reflected to *d*, and from *d* to *e*, and from *e* to the ear at *b*. So it will be with all the aliquot, or even divisions, of the semi-circle *a*, *c*, *d*, *e*, *b*; as well as the other half, *a*, *g*, *b*; so that it may be

said that not an atom of any wave that strikes the wall is lost, but that they all assemble at the ear *b*; consequently, the sensation is as if the mouth and ear were close together. But if the ear and mouth are not diametrically opposite, the words will be heard double; for one arch being less than the other, the sound will arrive at the ear sooner round the shorter arch than the longer.

Water is an excellent conductor of sound, and greatly assists echo. The remarkable echo of Simonetta, near Milan, is over arcades of water. Another, near Rouen, is over subterraneous caverns of water. In calm weather a whisper may be heard across the Thames.

Sound is capable of being condensed in a tube, or speaking trumpet, so as to penetrate through the air to a great distance, in one line. For all the waves that fly off globularly from a sounding body, are by this trumpet condensed into one line, and, therefore, its force becomes great in proportion. The mouth of this trumpet opens (or should open) in the logarithmic curve: this curve has the property of reflecting the waves, that struggle to disperse at the mouth of the trumpet, into the axis of the instrument, as represented by the spotted lines, Fig. 48, agreeably to the law of the angle of incidence and reflection in Optics. This is the trumpet's effect both in receiving and delivering sound; for waves striking the mouth of the trumpet, B, from without, become condensed in the tube, and strike an ear at *c* with the compressed force of all the waves that cover the mouth of the trumpet: hence its effect in assisting deafness. If two trumpets, as A and B, be placed in the axis of each other (as in the figure) at forty or fifty feet distance,

the smallest whisper at *a*, would be heard distinctly by an ear placed at *c*; and *vice versâ:* so that a person might ask a question at *a*, and receive an answer from *c*. The answers seemingly given by the suspended *Speaking Figure*, is a trick founded on this principle.

Two bodies of air, striking against each other, produce thunder; for lightning either bursting in, or darting through the air, will separate it, and cause a vacuum; so that the separated bodies of air coming together, and striking progressively against each other, cause the long-reiterated report of thunder: reverberation from clouds, mountains, &c. also contribute to this effect. So it is in the report of a gun: flame, by its repulsion, universally displaces the air; the rarefaction of both air and the moisture produced in firing gunpowder, contributes to extend the vacuum; hence the quick return of the air into the gun makes it strike the bottom of its barrel with a force capable of producing a loud report; for it must be remembered, that in proving the particles of air to be hard, a column of air was suffered (in the first Lecture) to fall on the plate of an air-pump, which produced as loud a report as that of a common gun. Hence also the reason why an air-gun can scarce be heard; for the displaced air, returning, falls on a cushion of rarefied air within the barrel.

If a rope be stretched tight between two points, thirty or forty feet distant from each other, as *a* and *b*, Fig. 49, and struck with a stick, the whole rope will not vibrate, but several still places will be seen in it, between which the parts of the rope will vibrate, as from *a* to *c*, and from *c* to *d*, &c. The distance of these stationary places is always an even or an aliquot part of the whole rope; as

from *a* to *c* is half its length; from *b* to *d*, one-fourth its length, &c.

Hence arises the wild and wonderful harmony of the Eolian harp; for though the instrument may have twenty strings, all tuned unison to one another, yet do we hear not only the natural sound of each string, but its octave, fifth, third, twelfth, fifteenth, &c. A current of air is certainly a delicate fiddlebow; it affords a string (by the equable impulse upon its whole length), an opportunity of dividing itself into a number of imaginary bridges, to which it has a natural tendency. Hence every string becomes capable of three, four, and more sounds; thus *a*, *b*, Fig. 50, are the usual bridges of the string *a*, *c*, *b*, from whence the string has its natural key: the most important imaginary bridge is at *d*, which is in the middle of the string: half the string having but half the *vis inertiæ* of the whole string, will, therefore, vibrate twice as fast as the whole string; every second wave, therefore, coming in contact with waves of the original string *a b*, gives a pleasing sensation to the ears, and the union is called an octave. Another bridge takes place at *e*; the vibration of *a e* is thrice, while the whole string is twice; hence every third wave of *a e*, coincides with every second wave of *a b*, and produces the concord called a fifth. The remaining part of the string *e b*, being half the length of *a e*, is, of course, an octave to *a e*, and a twelfth to the whole string *a b*. The part of the string *c b*, is seven-ninths of the whole string, and gives the major third to it, &c. Thus are the leading notes of the octave capable of being performed by one string, or one bell; such is the tendency that motion has to divide itself into proportional parts. The artful performer on the violin avails himself of this tendency, by gently

touching the aliquot parts of a string; by which he assists nature in forming the bridges, and produces those pipe-like tones called harmonics.

The pulsations, or waves, caused by the quick vibrations of a string, or bell, may be further illustrated by the mechanical sympathy among accordant sounds, viz. If two strings, on two instruments, are tuned unison, and one be struck, at several yards distance from the other, that other will reply; for the waves made by the first string being the same that would be made by the second if struck, those waves give a mechanical stroke to the second, and produce its sound.

2d. So in the Eolian harp, if only two of its strings are unison, and a piece of paper be hung on one of them, all the other strings may be struck without effect; but when the unison string is struck, the paper is instantly shaken off.

3d. In like manner, when the dampers are taken from the strings of a piano-forte, the instrument will repeat the key of every word spoken in the room.

4th. A wet finger pressed round the top of a wine glass, will produce its key; or if it be struck with a small key, its *pitch* will be produced. An unison, or octave, to that pitch being strongly excited on a violoncello, the glass will begin to dance, and, perhaps, be shaken off the table.

5th. Those unacquainted with this mechanical sympathy, are much astonished to see a loose pannel in a wainscot begin to dance

in its mortice, when a particular note is produced on an organ; but if they strike the pannel, they will find it unison, or octave, to that particular note.

6th. This sympathy is not confined to inanimate nature; a dog will begin to howl at one particular note, when he is totally indifferent to the rest of the seven. May not the dog and other animals have a key, as well as a drum, a tambourin, or a brass kettle?

7th. The drum, the cochlea, and labyrinth, of the human ear, abound with fibrous nerves—too delicate and pulpy, indeed, to be capable of tension, like a musical string; but they must have great variety of divisions, as connected with the cochlea; and the cochlea may be considered as a musical instrument. If the interruptions in these nerves be in harmonic intervals (as is more than probable), may not their sympathy with external sounds cause our perception and discrimination of different sounds? and may not the different formation of the cochlea, in different people, be the reason why some are blest with a musical ear, and others not? The waves of the air are propagated up the meatus auditorius, and give a mechanical stroke, or impression, to the auditory nerves; so that hearing may be said to be a species of feeling, as a stroke, or impression, on the eye, produces the sensation of light.

Every kind of elastic body is a conductor of sound as well as the air. If the ear be held to one end of a long stick, a beam, or a fallen tree, and the smallest scratch be made at the other end, the scratch will be distinctly heard by the ear. But the air is the general conductor of sound; it pervades all places, and is there-

fore most proper, as being present to the ear wheresoever situated. If a bell, *a*, Fig. 51, be hung in a glass receiver on the air-pump, and the air exhausted, no sound can be heard when the bell is rung: for if it hangs so that the wire trigger *c*, acting through the collar of leathers *d*, can move the pin *o* (fixed to the top of the bell), the bell may be rung in vacuo as well as in the open air. This experiment proves the air a conductor of sound.

2d. The metallic round box *a*, Fig. 52, is screwed close to the brass plate *b*, on the thread of the collar of leathers *c*. In the box is contained a little gunpowder, which can be shoved over the hole *z*, by the arms *o o*. These arms are actuated by the wire *w* going through the collar of leathers *c*; so that, by being turned round, the gunpowder falls through the hole *z*, on the red-hot iron *x*. This being performed in vacuo, as in the last experiment, the inflamed powder *makes no noise*. But as no flame can be produced without air, it may be asked how gunpowder can be ignited in vacuo? It carries its own air along with it; for nitre, when heated, produces more than one hundred times its bulk of vital air; and nitre is one of the principal ingredients of gunpowder. Hence the flame at *x* having no air to displace around it, the inflammation is silent; but when the air is let into the receiver, a few grains would blow up the box and plate *b* with a loud noise: that noise would be greatly increased if the air was condensed round the hot iron, or the bell, in the former experiment. A bell may be heard under water tolerably well; but its pitch or key will not be the same as in air; it will be a fourth deeper.

As sound travels 1142 feet, or about a quarter of a mile, in a second; and as a person in health has about 70 pulsations or beats

of the artery at the wrist in a minute; this approaches so near to a quarter of a mile for every pulsation, that if the flash of a gun at sea, in the night, was seen eight pulsations before the report was heard, the ship may be concluded to be about two miles off.

Spongy bodies, as woollen cloth, absorbs sound; hence music or oratory are ill heard behind a number of people.

Different kinds of air produce different sounds, though all nearly of the same loudness. Air pressed from a bladder through a small pipe into vital air, gives a sound half a tone lower than when pressed into atmospheric air; the same effect takes place when the pipe sounds in azotic air; but when these two airs are mixed in the proportions they are said to bear in the atmosphere, the sound is the same as in the atmosphere. Injected in inflammable air, the sound is ten or twelve tones higher; in fixed air, one third lower; and in different airs not uniformly mixed, intolerably harsh and discordant. These effects seem to arise from the different weights of these airs.

Fig. 17.

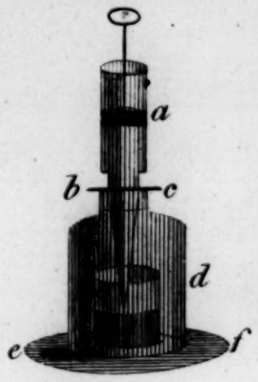


Fig. 3.



Fig. 13.



Fig. 6.



Fig. 5.



Fig. 10.

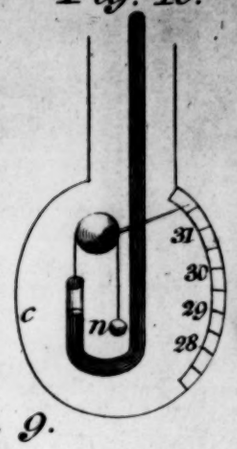


Fig. 16.

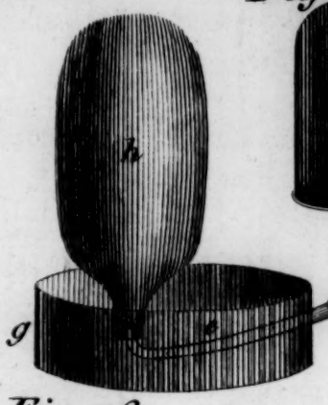


Fig. 20.



Fig. 14.



Fig. 27.



Fig. 1.

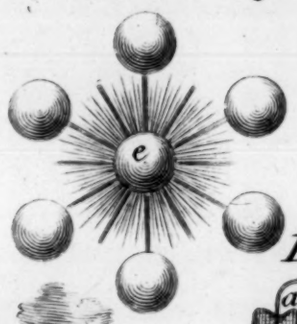


Fig. 7.



Fig. 29.

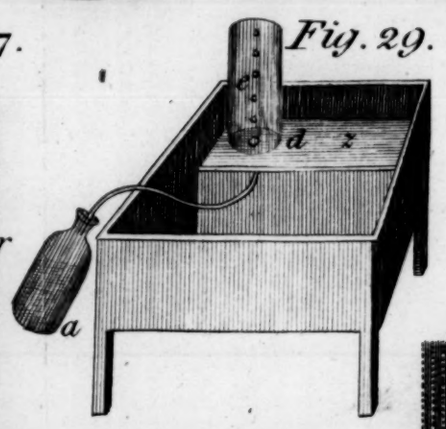


Fig. 4.



Fig. 2.

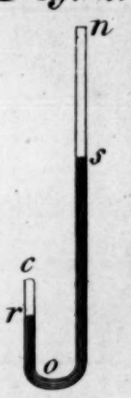


Fig. 24.

Fig. 19.

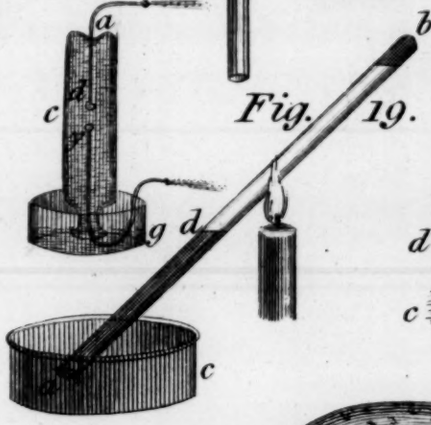


Fig. 8.



Fig. 26.



Fig. 25.

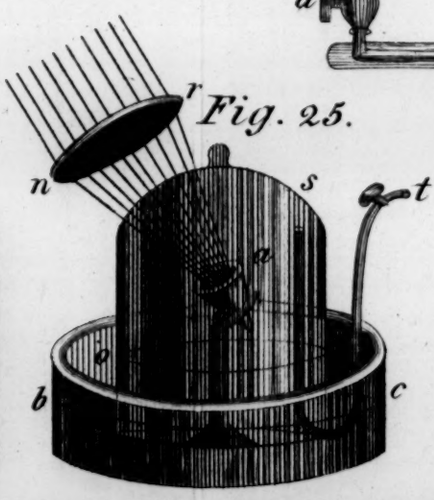


Fig. 15.

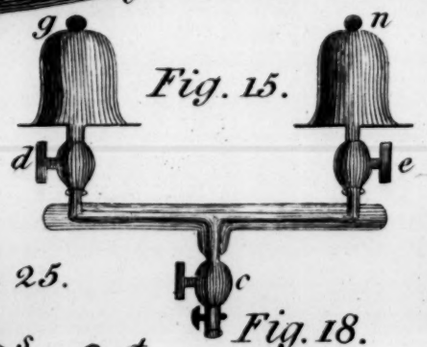


Fig. 18.

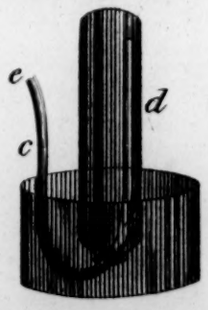


Fig. 11.



Fig. 23.



Fig. 21.

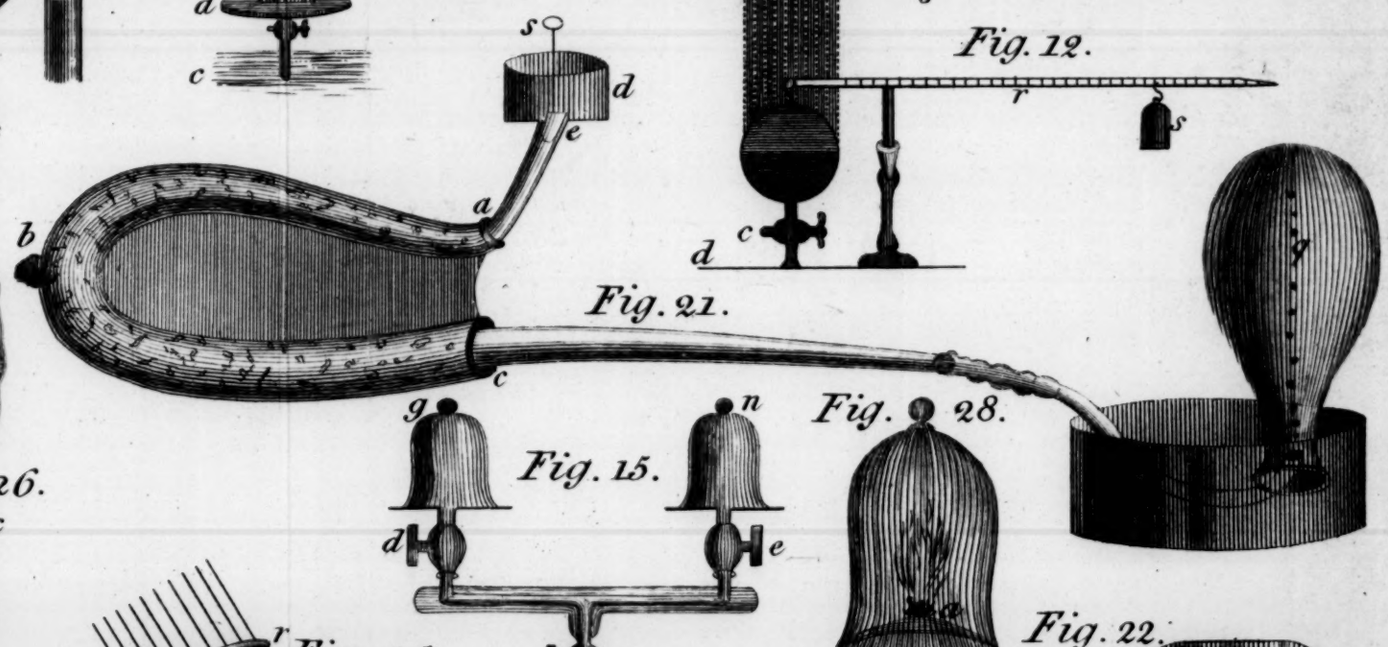
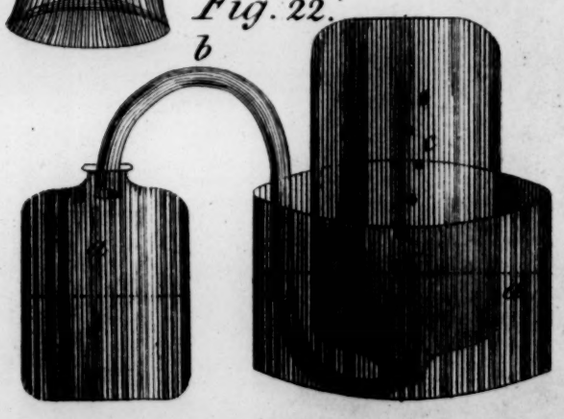


Fig. 12.

Fig. 28.

Fig. 22.



Barlow sculp.t

Fig. 30.



Fig. 31.



Fig. 32.



Fig. 33.



Fig. 34.

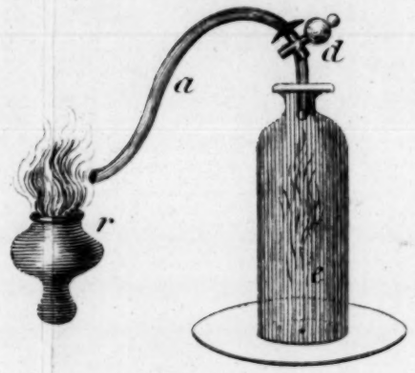


Fig. 35.

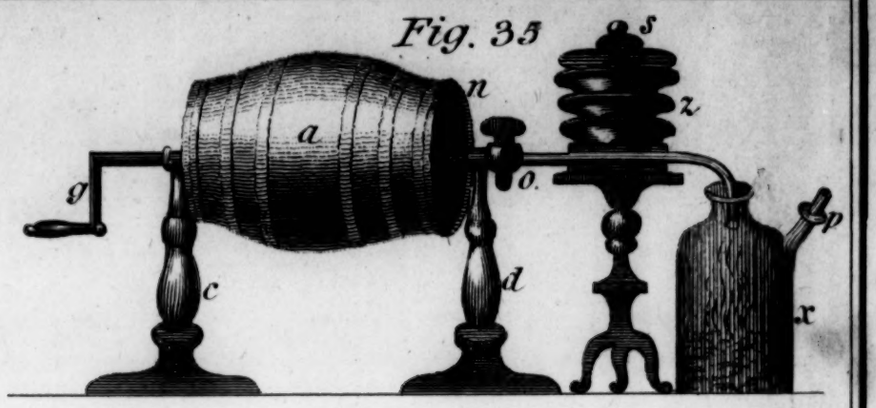


Fig. 36.

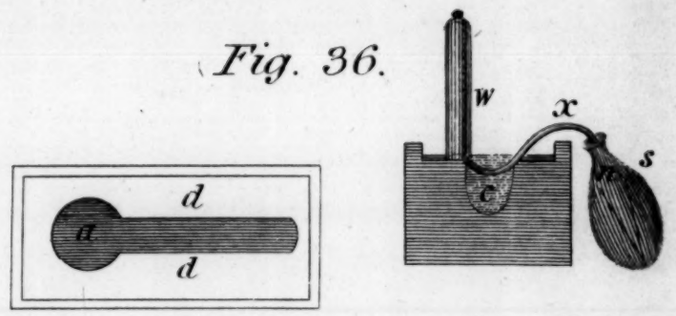


Fig. 37.

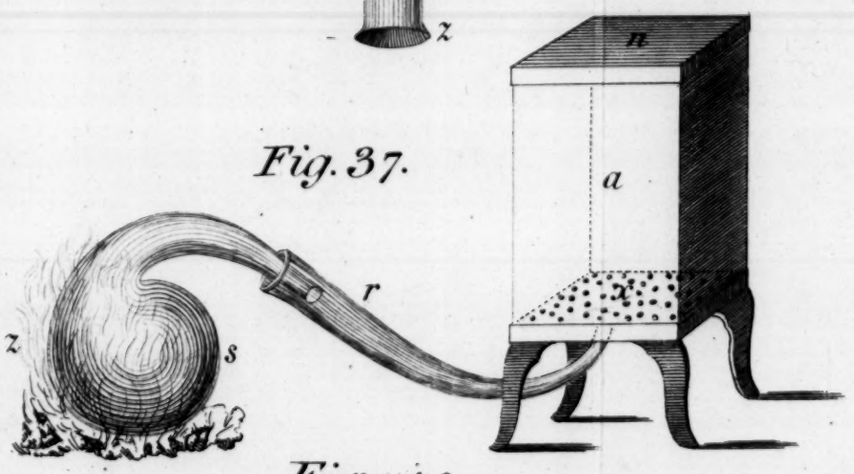


Fig. 38.

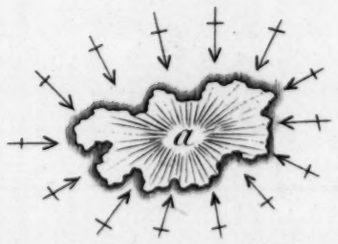


Fig. 39.



Fig. 40.

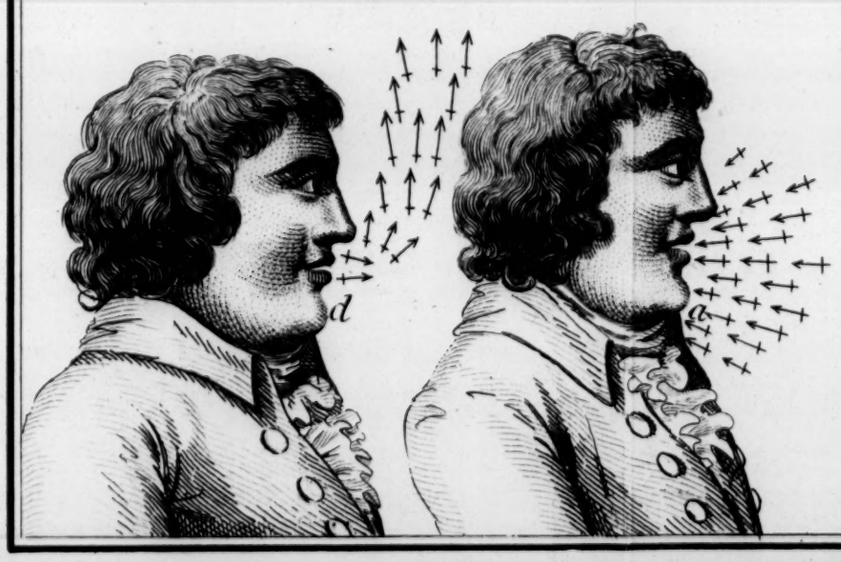


Fig. 41.

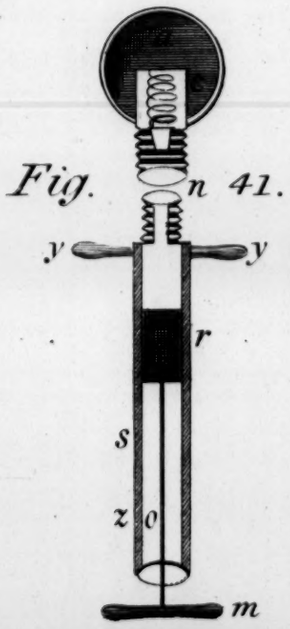
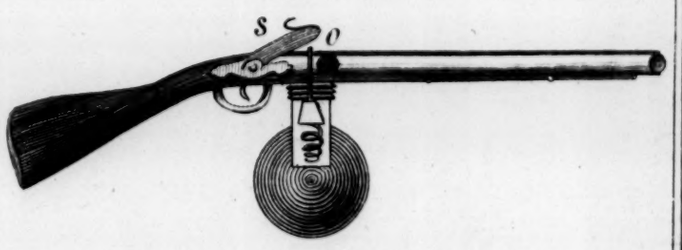


Fig. 42.



Barlow sculp

Fig. 43.

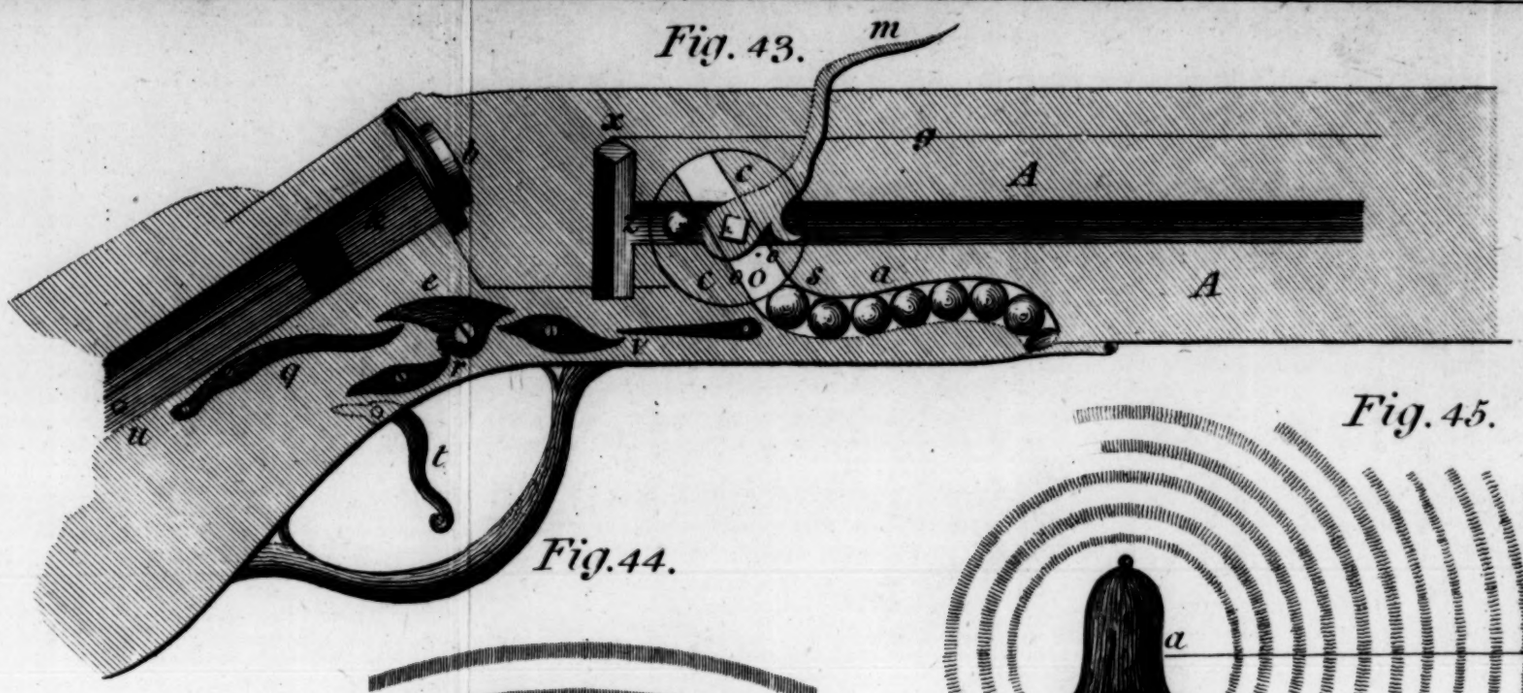


Fig. 44.

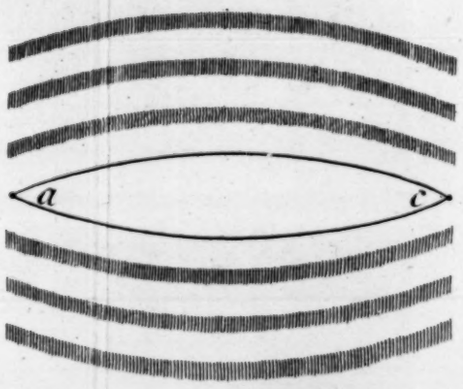


Fig. 45.

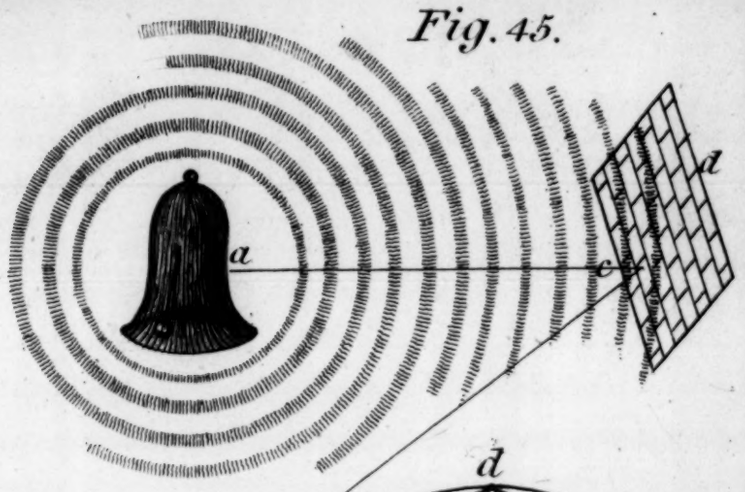


Fig. 46.

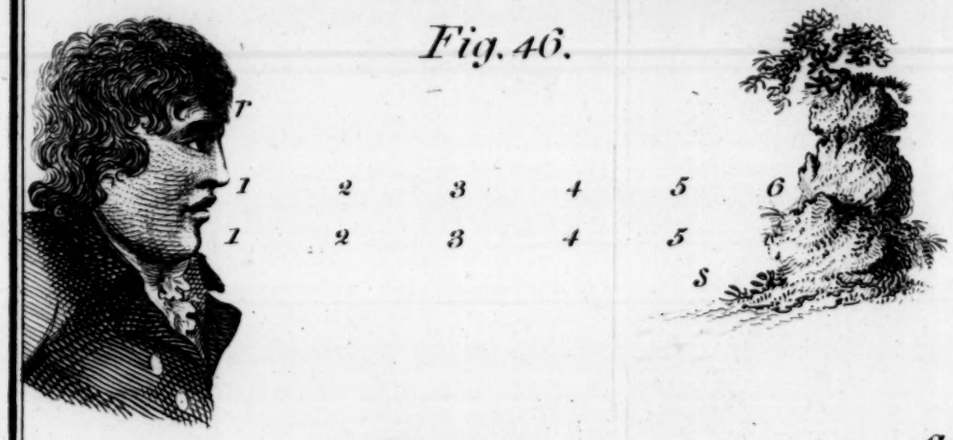


Fig. 47

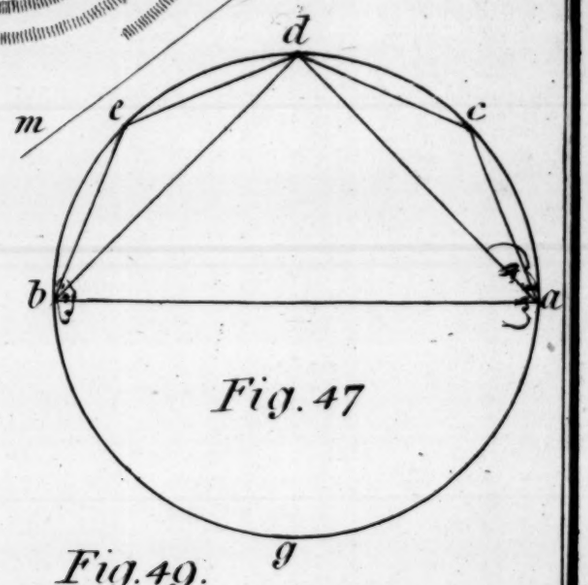


Fig. 48.

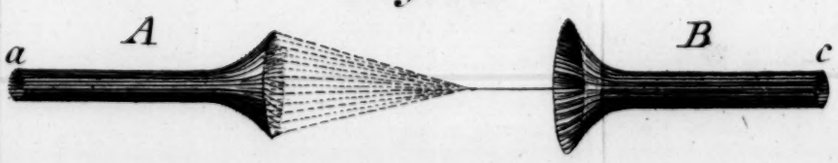


Fig. 49.



Fig. 50.

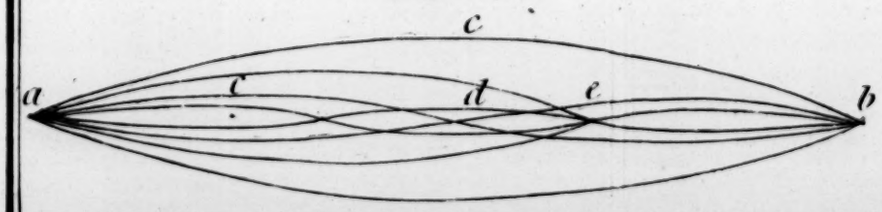


Fig. 51.

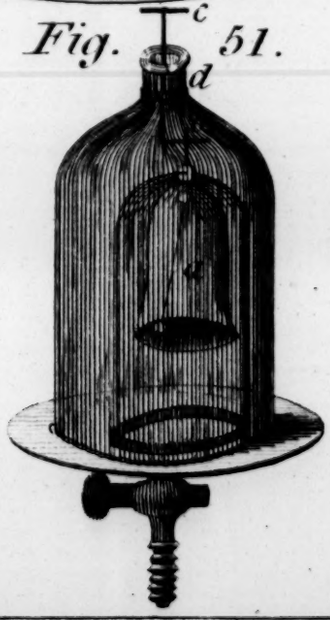
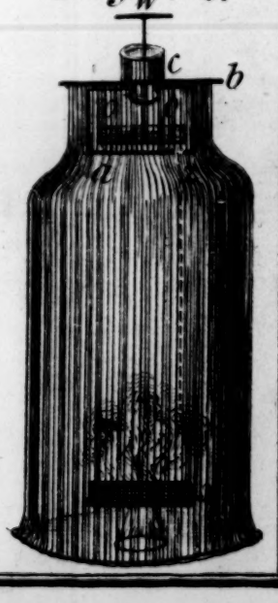


Fig. 52.



Barlow sculp.

LECTURE VI.

HYDROSTATICS.

THIS branch of natural philosophy treats of the action, the motion, and pressure, of fluids in general: but the mechanical properties of water is its principal object. By observing that this fluid is capable of imbibing a large quantity of salt, sugar, &c. without having its bulk increased, and that aquatic plants have round pores, it has been imagined that water is formed of round particles, touching one another (and, therefore, incompressible), but infinitely too small to be seen. To make a picture of this idea, the larger balls, Fig. 1, represent water, and the smaller, salts, or other particles that can insinuate themselves into the pores, or interstices, of the bigger balls. This idea is a little strengthened by the different characters of water, such as mineral waters, medicinal waters, and such as imbibe the fine particles of stones in the bowels of the earth, and the particles of air from the atmosphere; stript of these, we find the *simple element* the same in all parts of the world; and, therefore, it must derive its various characters from particles taken into its pores, or interstices. One principle, however, we are sure is united with it, and that is light, or fire, but not so as to be obvious to our senses; it gives it fluidity, and, without increasing its bulk, resists the cohesion of its particles: hence the

ease with which they slide over one another, in the fluid state, and the solid form they assume when fire is detached from them. This ease with which the particles of water slide over one another, and yield to the lightest impression, constitutes one of its characteristics as a fluid; and is the reason why its surface is so liable to be harrowed up into waves. It shews also how they give way, when any light body swims on their surface; and when in rapid motion how they rise above their level when met by a solid, or any resisting body; for water is the slave of inertia as well as all other matter. If water, then, can be allowed to be formed of pillars of round particles, we may account for the swimming of lighter bodies in it; these bodies press down the pillars underneath them, and make the neighbouring ones rise in proportion, till a balance is restored; so that if the bed made by the swimming body was filled with water, that water would be exactly equal in weight to that of the swimming body. That is to say, *every body that swims in water, just displaces so much water as is equal to its weight.*

1st. I put a small model of a boat in one scale, Fig. 2, and balance it with water in the opposite scale *a*. I then remove the boat into a bason filled with water, Fig. 3, and the water it displaces will run over the edge of the bason; if then the water in the scale *a* be poured into the bason, and replace that which the boat forced over its edge, the proposition is proved, that every thing that swims on water just displaces so much water as is equal to its weight. If, therefore, a person lay in the bottom of the Thames, when a ship sailed over him he would feel no more pressure than he would from the weight of the water which supplied its place.

2d. I tie a piece of bladder (a little flaccid) over the end of the open glass cylinder *c*, Fig. 4, so that it will hold water, and fill it

up to *a b*; I then immerse it in the vessel *n o*, filled with water to *r s*. If then the surface of the water in the inner cylinder *a b* be pressed even with the surface *r s*, the bladder will be flaccid, even, and horizontal, as *d e f*. But if the inner cylinder be lifted up, so that the surface *a b* shall be above *r s*, then will the bladder be pressed concave downwards, as *d m f*. If then the surface *a b* be thrust beneath the surface *r s*, the bladder will be forced convex upwards, as *d w f*. Do not these experiments prove that water presses upward, as forcibly as it weighs downward, according to its perpendicular height? For, when the two surfaces are even, the bladder is neither pressed up nor down, shewing, that there is an agent underneath it, equal in force to the weight of water above the bladder, &c. This agent is the returning pillars of water, endeavouring to rise to the level of the water, in the outer cylinder.

3d. The action of these returning pillars may be better understood by Fig. 5, where *a* represents a glass cylinder, open at both ends, *b* a string by which a thick piece of lead may be held fast to the bottom of the cylinder: to prevent the water getting in between the lead and the glass, the lead is first covered with wet leather. If then (with the cylinder in one hand, and the string in the other) the lead and cylinder be plunged in the vessel of water *c d*, to the depth of six or eight inches, the string may be let go, and the lead will be pressed so fast to the cylinder, that no water can penetrate between them. What presses it? The short pillars of particles underneath it, influenced by the tall pillars *e n* and *o m*. Hence it may be seen how lead may swim, and vessels that are specifically heavier than water, provided they are so formed as to displace as much water as is equal to them in weight. Ships sink when full of water, because they do not in that state displace so much water

as is equal to their weight: when swimming, they do. But if the cylinder and lead were lifted up as high as the line *g g*, the lead would fall off, and break the outer jar, if not prevented by the string. Shewing that water presses according to its perpendicular depth, and *that* in all directions alike; for if the several crooked tubes, Fig. 6, have their upper end stopped by the thumb, and immersed in a jar of water, so soon as the thumb is removed, the water will instantly rise in them to the level *a c*. Or if a vessel, Fig. 7, be filled with water, and the orifices *a* and *b* (bored with the same tool) be both opened at the same instant, they will discharge equal quantities in the same time: proving that water presses laterally, or side-wise, as forcibly as downwards, according to its perpendicular height.

4th. The particles of water sliding over each other with such excessive ease, it is evident that if I stop the end of the crooked tube, Fig. 8, at *a*, when full of water, the water will press against my thumb at *a*, with a force equal to the weight of water contained in the tube between its top *b* and the level with my thumb *c*; for the instant I remove my thumb, the water falls to the level *c a*: *n a* may therefore be conceived as one of the returning pillars that pressed the bladder, and supported the lead in the second and third experiments.

5th. But if, instead of one returning pillar, we make some thousands, as in the case of the hydrostatic bellows, the power becomes excessive with a small quantity of water, Fig. 9. This machine is made of two strong round boards united by strong leather, in the manner of common bellows, but nailed so tight to the edges of the boards as to hold water, see Fig. 9: *a* is a pipe of any height leading into the inside of the bellows. If water be

poured into this pipe, the upper board will soon begin to rise and lift the weight *w*: and if the pipe was tall, and that board wide enough, it would lift the man who poured in the water. If, when the bellows are full of water, weights were laid on them till the water was forced up to the top of the pipe *a*, those weights would express the weight of a pillar of water, whose base was equal to the area of the under board of the bellows, and whose height was from that board to the top of the pipe *a*; which may be better understood by the spotted line in the figure. It is evident from what was said of the last experiment with the crooked tube *b c n a*, that the returning pillar *n a* would press as forcibly against the bottom *n* by reaction as the tall pillar *b n* by its weight; for the pressure against the thumb *a* was equal to the weight of water between *b* and *c*, and therefore the reaction of the short pillar upon *n* would be equal to the weight of the tall pillar. This reasoning carried to the bellows will account for the weight they lift; for the water within the bellows is all returning pillars (like *n a* when the pipe *a* is full), each endeavouring to rise to the level *e n*, and thrusting against the lid with a force that would bring them to that level, if they had an opportunity. But if, instead of the pillar of water *e o*, acting on the bellows by its weight, that water was *forced* in by a piston moving in *e o*, the bellows, if strong enough, would lift a house! On this principle a press is formed of immense power. Fig. 10, *a* is a strong cast-iron cylinder, ground duly circular within; *e* is a piston fitting very tight into the cylinder; *c* is the piston of a force and a sucking pump, which, by its ascent, draws the water out of the cistern *d* through the valve *n*; by its descent the valve *n* shuts, and the water above it is forced through the valve *o* into the cylinder *a*, and drives up the piston *e*; this forms a pressure at *m*, by the force of one man working at *s*, that squeezes cotton bags, hay, &c. into twenty times less compass than they

generally occupy. We see, from these experiments, why the banks of ponds and canals are so liable to blow up, as it is called; for if water can insinuate itself under a bank or dam but the thickness of a shilling, when its head is high, even banks of stone have been blown up as if a train of gunpowder was fired beneath them. Suppose *a*, Fig. 11, a section of the bed of a river, and *c* a land-drain under or through one of its banks; compare the tall columns of water *d e* to the short ones in the drain, and it will be easy to conceive, that if the part of the bank *g* be not as heavy as the columns *d e* (as water presses in all directions alike according to its perpendicular height), that part of the bank will blow up. This effect is prevented by *puddling*, as it is called; that is, cutting a trench lengthwise of the ditch, about eighteen inches wide, and a little deeper than the canal, or reservoir, as *n m*; this is filled by a little at a time with clay, or common earth, in a semifluid state by water; when the first is nearly dry, a little more is poured in, and so on till it is filled: this makes ponds, ditches, canals, docks, or reservoirs, as staunch as a bottle.

6th. The hydrostatic paradox, as it is called, may also help to illustrate this doctrine. A brass cylinder, of which *a b*, Fig. 12, is a section, has a piston *c*, that fits it so that it can easily move up and down in the cylinder by the rod *d*; *e f* is a cylinder of glass, cemented into the brass collar *g h*, and screwed on the brass cylinder. The balance being now applied to the chain part of the rod *d*, the whole is filled full of water; but as part of the water will be lost at the piston *c*, and pass through the hole *q* (for the piston must not be water-tight, as its friction would hurt any conclusions that could be drawn from the experiment), water must be kept easily pouring in, while the column is having its exact weight ascertained in the scale of the balance. When this is exactly done, the glass cylinder

is unscrewed from the brass cylinder, and the conical glass A screwed in its place, Fig. 2, No. 2: this glass is exactly the same height as the cylinder *e f*, but will hold ten times as much water: should it not then weigh ten times as much on the plug *c*? Yes, it would, if it were frozen, for then the whole would be lifted. But the same weights which lifted the column contained in *e f* will lift the water in A; but not all the water: it will lift only the column *r s t u* through the middle of it; or rather a column, whose base is the piston *c*: the rest of the water in A is sustained by this pillar and the flanging side of the conical vessel. In reality, then, there was no more water on the piston in the second than was in the first experiment. But will it not appear still more paradoxical, if the water that can be contained in the small pipe B, Fig. 13, shall form as great a pressure on the piston *c* as all the water that was upon it in the last experiment? It is even so. Let the cap *z o* be screwed in the place *g h*, and the rod *d* pass through the small tube B; if now it be filled with water, the weights will be overcome, and the piston forced down exactly as in the last experiments: this is done by the returning pillars within the brass cylinder *a b* pressing against the lid *z o*; for as action and reaction are equal, and contrary, with what force soever the short pillars press against the lid *z o*, they will react with the same force against the piston *c*. Now these short pillars are all influenced by the tall pillar of water in B, and would all rise up to the top of B, if not stopped by the lid *z o*, then would they act by their weight instead of their pressure, as in the first experiment. This seeming paradox may be further aggravated by inverting the conical vessel A, Fig. 12, as Fig. 14, in which case we affirm there is as great a pressure on the bottom *a b*, as would be if the whole cylinder *a b c d* was filled with water. We must still keep in mind the nature of

fluidity; that its particles slide with the utmost ease in all directions accordingly as they are pressed; consider then (as in the last experiment) the influence the long pillar *h n g e* will have upon the short ones, such as *z y*, *o r*, &c.; that these will be pressed against the sloping side with a force that would raise them to the height of the tall pillar, if that side did not stop them; and, consequently, that they will have a reaction against the bottom equal to the gravity of the tall pillars. The pressure of the water, therefore, differs from its gravity in this respect: the gravity of water is according to its quantity; the pressure of water is according to its perpendicular height: this pressure is independent of quantity; a pipe six feet high, and one inch in diameter, would be as liable to be burst as a cylinder of six feet high and six feet diameter, equally strong.

7th. This pressure increasing like the acceleration of falling bodies, is a beautiful instance of that sameness and simplicity observable through all the laws of nature; it is as the odd numbers 1, 3, 5, 7, 9, 11, &c.; that is, if Fig. 15 represents a tall square vessel full of water, five inches deep, and one inch square, the pressure against one of the sides of the topmost inch will be nearly one ounce; against the same quantity of surface below, *three* ounces; against the inch below, *five* ounces, &c. Now this is as the square of the depth; i. e. against the two upper surfaces there is a pressure of *four*; against three of the upper surfaces there is a pressure of *nine*; against four of the uppermost surfaces there is a pressure of *sixteen*; and against the whole front surface, five, there is a pressure of *twenty-five*; for 9, 7, 5, 3, 1, added together, will make 25, and five times five is twenty-five. This may be proved by a simple machine, Fig. 16, made of the same height as the last. The two pieces of inch-board *a* and *b* are mortised into one another,

and have grooves at an inch distance, to receive two panes of flat window glass, which are made water tight with putty in the frames *a* and *b*. A thin board *c* hangs by two hinges on the corners of the two panes at *n*, and covers the edges of the panes to the bottom. This board is held to the edges of the two panes by the weight *w*, and is covered with cloth to hold water. Now as the machine is open at top between *n* and *m*, water may be poured in there; and, if one ounce is hung at *w*, the door *c* will be forced from the edges of the glass, when the water rises to the line 1. If four ounces are hung at *w*, the door will be opened, and the weight lifted, when the water rises to the line 2. If nine ounces be hung at *w*, the water will press off the door when it rises to the line 3, &c. shewing that the pressure is as the square of the depth; and giving a rule by which may be estimated the pressure of water against embankments, flood-gates, reservoirs, &c. and also demonstrating, that if water were twice as high on one side of a flood-gate as on the other, the pressure would be four times as great: also, that the side of a cistern is as forcibly pressed as the gate of a large dock, if the perpendicular height of the water, and the area of the surface pressed against, be the same.

8th. Spouting pipes are subject to the same law. Pipes of the same length and bore discharge water according to the square root of the depth beneath the surface; i. e. the pipe *b*, in Fig. 17, will discharge twice the quantity in the same time as the pipe *c*, though bored with the same instrument, being four times as far below the surface. One nine times as far beneath the surface, would discharge three times as much water in the same time, as the pipe *a*, &c. the vessel being kept full.

9th. The law by which a head of water will force water through

pipes of equal bore, at different heights, is another instance of the mathematical uniformity of nature. Let *a b*, Fig. 17, represent a tall pillar of water, whose head at *a* must be kept to that level during the experiments. On the middle of this pillar place one leg of a pair of compasses, and draw a semicircle, whose diameter is the height of the pillar of water. It is remarkable that the pipes both above and below the middle will throw water to an horizontal distance proportionate to the sines of this arch; i. e. the sine *c d* is equal to the sine *g h*, and their respective pipes throw water to the same distance. The radius *i k* may be considered as the longest sine of an arch, and its pipe will accordingly throw water to the greatest horizontal distance of any similar pipe that could be fixed in any part of the pillar between *a* and *b*. The water being still kept up to the level of *a*, if the three pipes *n*, *m*, and *o*, be opened at bottom, *o* making an angle with the horizon equal to 22° 30′; *m* an angle equal to 45°; and *n* equal to 67° 30′; they will each throw water to an height according to their respective sines; i. e. the pipe *o*, to *h*; the pipe *m*, to *k*; and the pipe *n*, to *d*; their horizontal distance also will exhibit a wonderful conformity: the water that touches the sine *g h*, and that which touches the sine *c d*, fall at the same place with the waters of the pipes *c* and *g*; and that which touches the longest sine *i k* spouts to the greatest distance, and falls at the same place with water from the pipe *i*. Hence a mortar, or great gun, elevated to an angle of 45°, will throw a ball to a greater horizontal distance, than it will in any other angle. This is theoretically true, but not quite practically so; for wind, a greater or less density in the air, &c. will make a small difference; and so it will in the spouting fluids; the common resistance of the air making each parabola a little more perpendicular on its right hand side than on its left.

10. The resistance of the air is also the reason why water will not rise so high in a jet as in a tube. Fig. 18 is the last-used pillar full of water; if a small pipe *c* be opened, the water will rise only to *a* in the character of a jet, but it will rise to the level *d* in the tube *t*; and let that tube be inclined in any angle, the water will rise to the level *d*, if the tube be long enough; or, in case the pillar was empty, and water was poured into the tube *t*, the water in the pillar would keep on a level with the water in the tube: shewing that fluids universally will rise to a level, let the pipes of conduct be long, short, square, round, big, little, or crooked. Why does not so heavy a body of water as is contained in the pillar force up so light a body as is contained in the tube higher than the level? Gravity, and the flexibility of the pressure in the fluid, accounts for this. If no tube were joined to the pillar, the water would be at rest, and held quiet in it, by the power of gravity; but now we join the tube *t* to it, and open the stop-cock *e*; instantly the fluid becomes less pressed at this opening, than by the sides of the pillar, and the particles sliding over one another with such ease, the weight of the water in the pillar will squeeze up that in the tube to its level. But why not higher? Because, in reality, it is but a column of water in the pillar, of the same thickness as the tube, that can operate upon the water in the tube; all the rest of the water is supported by the bottom of the pillar, and the projecting reservoir at top; so that it is but the effect of an inverted syphon, and may be represented by an imaginary pillar going through the water, and joining to the tube *t*, making the syphon *d e t*.

11. Water thus rising to its level, affords us a means of conveying it across vallies without those expensive aqueducts erected by the ancients for that purpose, whose ruins remain the wonder of our own times. A pipe, conforming to the shape of the

valley, will answer every purpose of an aqueduct. Suppose the spring at *a*, Fig. 19, and I want its water on the other side of the valley D, it is evident, from what has just been proved, that a pipe of lead, or iron, laid from the spring-head across the valley, will convey the water up to the level of the spring-head; but, by a survey, I find the house rather lower; a constant stream will, therefore, pour into my cisterns and ponds, as if my house were on the other side of the valley. In this case a regard must be had to the depth of the valley; for as the pressure of water increases in the rapid ratio of 1, 3, 5, 7, &c. if the valley be deep, the pipes must be made very strong near its bottom, or they will burst.

Of Specific Gravities.

THE specific gravity of a body is its weight, when compared with the weight of its bulk of clear rain-water. The specific gravity of quicksilver is said to be fourteen; because a cubical inch of quicksilver, put in one scale of a balance, would require fourteen cubical inches of water in the other to balance it. So the specific gravity of copper is eight, because one cubical inch of copper will balance eight of water. The density of bodies, therefore, composes their specific gravity, as may be better exemplified by three cubical inches of wood of different density; one will swim a-top, another sink to the bottom, and another remain at rest in any part of the water; the first, then, is said to be specifically lighter; the second specifically heavier; and the third of the same specific gravity as water. Water being thus made the standard of comparison, respecting the density of different bodies, a table may be made of the different substances in nature compared with water; with one another, and with themselves. See Table of Specific Gravities.

It may be seen in the table, that there is great variety of density in bodies that bear the same name. Glass, for instance, is above twice as heavy as its bulk of water; some three times as heavy; and some almost four times. Cobalt has great variety; some is six, and some eight, times as heavy as its bulk of water. Diamonds have no variety; zinc and lead very little; sterling gold is seventeen and three quarters heavier than water; and pure gold from nineteen to twenty times heavier.

As one cubit foot of pure water is equal to 1000 ounces avoirdupoise, this becomes a standard for finding the specific gravity of bodies, whether heavier or lighter than water.

It having been already proved, that every thing that swims in a fluid just displaces so much of that fluid as is equal to its weight; on this axiom is founded an instrument called the *hydrometer*, for measuring the specific gravity of fluids. This is generally an egg-like bulb of glass, ivory, or copper, with a thin graduated stem, made small a-top to receive a weight *g*, which will sink the hydrometer to a certain depth in proof spirits, as Fig. 20. Now a proof spirit is generally supposed to be one-half of its weight a pure spirit, or alcohol, that, if set on fire, would all burn away, and the other half water: or, that one gallon of it should weigh seven pounds twelve ounces, when the thermometer stands at 55°. As bodies that would swim in water, would sink in spirit of wine, the weight *g* should be filed, or diminished, till it sinks the hydrometer to the middle of the stem; and figures above and below that middle should denote how much the compound is above or below proof: for if it is below proof, that is, if it has more water than spirit, its buoyancy will be too much, and the proof-mark will be thrust above the surface; if above proof, the mark will sink below the surface:

and in both cases, to figures that should indicate how much water, or spirit, there is, more than the standard. But though this instrument is founded on philosophical principles, it is liable to much fallacy. For, in the first place, spirits and water form a very different penetration with each other, at one stage of their mixture, to what they do at another. A pint of water, added to a pint of water, will make a quart; and a pint of spirit, put to a pint of spirit, will make a quart; but a pint of spirit, mixed with a pint of water, will not make a quart. See Hydrometrical Table. 2d. Rum or brandy, when warm, will sink the hydrometer, and appear stronger than they are: in extreme cold, or when mixed with a little sugar, they will appear weaker than they really are, &c. &c.

In this table may be seen how spirits and water penetrate each other in every stage of their mixture. The upright, or perpendicular scale, shews the specific gravity of the spirits, water being called 1000, and alcohol 830. The horizontal scale a-top, serves to determine how many gallons of water there is in 100 gallons of the mixture; and the curvilinear line, or scale, indicates the strength of the spirits, with respect to that standard called proof. For example: A spirit, whose specific gravity is 900, is composed of about twenty-eight parts of water, and seventy-two parts alcohol; or in 100 gallons of such spirit there is twenty-eight gallons of water, and that it is twenty-two gallons in 100 above proof, as indicated on the curvilinear scale.

This scale being founded on experiment, an hydrometer scale is formed from it, as seen on the right hand of the plate, where only a part of the bulb can be seen. This scale is made from trials, in which 100 parts of pure alcohol, and 100 parts of water, were mixed in this proportion, viz. ninety-nine parts of water, and one

of alcohol sunk the hydrometer to the first division of the scale. Ninety parts of spirit, and ten of water, sunk it to the ninetieth division. Ten parts of spirit, and ninety of water, sunk it to the tenth division, &c. &c.

It is curious to observe how different the penetration of the two fluids is at different stages of this admixture; as, for example, between the spirit-division of twenty and thirty, and the water-division between twenty and thirty. It may be seen also, that when there are between twenty and thirty parts of spirit, mixt with between seventy and eighty parts of water, that the two fluids form a more intimate union, and occupy less space than in any other proportion. Can the equal divisions, therefore, of the common hydrometer be true?

2d. I fill the bottle *a*, Fig. 21, with water, and placing my thumb on its mouth, invert it in a glass of red wine. The wine containing spirit, is specifically lighter than the water; so the heavy water descends into the glass, while the light wine rises to the top of the bottle in beautifully striated threads.

3d. Smoke rises in a chimney by the same law; though, of itself, it is only lighter than air while it is warm, and, therefore, rises little in the open air, and its gross parts soon precipitate back to the earth: it is heated air that carries smoke with such rapidity up a chimney. Fire heats the air on all sides, and sets its particles at an increased distance; hence the volume of air near a fire becomes specifically lighter than the colder air at a distance, and is by it buoyed up into the atmosphere. The heated air in a chimney, therefore, makes the pillar, of which it is a part, lighter than the

pillars of air at a distance. The heavier pillars, as *a*, Fig. 22, rush, therefore, through the fire to restore an equilibrium, and becoming rarefied themselves, are forced up the chimney by succeeding pillars: so that a perpetual current continues up the chimney so long as the fire continues, and becomes an useful ventilator for the room.

4th. Few land animals seem so helpless in the water as the human race; yet flesh and bones, and all together, we are specifically lighter than water; but so little, that, except we can lay with the face upwards, and have the mouth and nose *only* out of the water, we must make some effort to keep ourselves from sinking. In our usual mode of swimming we do not displace so much water as is equal to our weight, and are, therefore, under the necessity of turning our hands and feet into fins, to keep on the surface: in the exertion of swimming, we force too much of the body out of the water, and exhaust our strength in keeping it so. A ship water-logged, or nearly full of water, requires little pumping to keep her from sinking, the water within and without being so near upon a level; but when she springs a leak near the bottom, the pressure there is so great in comparison of what it is at the surface within the ship, that sometimes a whole crew cannot pump the water out as fast as it is pressed in. A man swimming is much in the same predicament; when he lies near the surface, the pressure upwards under his body is so much greater than the weight of water over his body, that being wholly immersed, he floats like a log, without any exertion; but if he dives a few yards beneath the surface, he will find difficulty in ascending, for in that situation (and so in proportion to the depth he dives) the pressure upon, and underneath, his body, will approach nearer and nearer to an equality;

and as his flesh and ribs are capable of being squeezed into less compass than they naturally possess, the excessive pressure of water, at a certain depth, will force his body into less bulk than its bulk of water: being thus specifically heavier, and that weight increased by the water forced into his stomach, and the pores of his skin, he sinks to the bottom. If a person sink slowly into water, a little effort will bring him back to the surface; but if then he does not throw himself on his back, and sink his head, but with violent struggling lifts himself so much out of the water as not to displace so much of it as is equal to his weight, he sinks accelerated; with much effort he may bring himself up again; but in making this unhappy voyage several times, his strength fails, he swallows much water, and then becomes heavier than the fluid.

Immerse a bladder, with a little air in it, in the pillar of water *a b*, Fig. 17; hang weights to it, so that it will just rise when thrust so far beneath the surface as *y*: if it be then thrust down as low as *z*, it will sink; for as the pressure of water increases in so swift a ratio as 1, 3, 5, 7, &c. it is evident that there is a greater difference (though not numerically) in the pressure of the depth between 1 and 3, than there is between 5 and 7, or 13 and 15, &c. for if a man near the surface of water has a force of 3 pressing upwards under him, and but a force of 1 pressing upon him, he will certainly have less pressure on his body than if 19 was pressing on, and 21 under, his body. For so great is the pressure of water at great depths, that if a bottle be corked ever so tight, and let down twenty or thirty fathom into the sea; the cork will be forced into the bottle. So if water is prevented from exerting its upward pressure upon a body, that body will be held down by the water upon it. Cement a piece of flat glass to a large flat cork, and press it down to the bottom of a vessel, with a flat bottom, full

of water, Fig. 23, the cork will remain at the bottom of the vessel for some time, till the water, by its pressure, gets in between the cork and bottom of the vessel, and then the returning pillars buoy it up to the surface.

Hydrostatic Balance.

Every body, heavier than its bulk of water, loses so much of its weight, by being suspended in water, as is equal to the weight of its bulk of water.

This useful axiom was discovered by the celebrated Archimedes; when, by the immersion of his body in a bath, he conceived the hint by which he detected the alloy in king Hiero's crown. He suspended the crown at one end of a scale-beam, and as much pure gold at the other, as balanced it: now, said he, there is an equal number of particles at one end of the scale-beam as at the other (supposing the separate particles of all matter of the same weight); but if you, Mr. Crown-maker, have mixed the pure gold with silver, or copper, the crown will be bigger than it ought to be (see Table of Specific Gravities), and, of course, more buoyed up in water. On the immersion of the crown in one vessel of water, and the pure gold in another, it was found to be so.

1st. I hang the conical piece of lead *a*, Fig. 24, at one end of a scale-beam; and a brass conical bucket at the other, which the lead *a* exactly fits. I fill this bucket with water, and put weights in the scale under it, till the lead *a* is balanced. If now I immerse the lead in a jar of water, that end of the scale-beam instantly rises, and shews the lead to have lost some of its weight: but the axiom

affirms, that every heavy body, suspended in water, loses so much of its weight as is equal to the weight of its bulk of water: now I have its exact bulk of water in the opposite scale; I pour this out, and an equilibrium in the balance is instantly restored.

2d. But suppose I wanted to know how much the lead was heavier than its bulk of water; or, its specific gravity. In this case I must weigh it, both in air and water. I find the lead weighs in air fifty-five ounces; but when it is hung in water, I find it requires five ounces to bring it to an equal balance; or, according to the last experiment, five ounces is the weight of its bulk of water; then so many times as five ounces are contained in fifty-five ounces, so many times is the lead heavier than its bulk of water, viz. eleven times, which is the specific gravity of lead.

3d. I have a silver candlestick, which I suspect not to be genuine silver. It weighs in air twenty-two ounces; but on being immersed in water (hung by a small thread), I find it loses 2.1 ounces; then 2.1 ounces is the weight of its bulk of water. But 2.1 ounces is contained in twenty-two ounces 10.4 times. Good silver is a little more than ten times as heavy as its bulk of water, therefore I become satisfied with my candlestick.

4th. A new guinea should weigh 129 grains; but it may weigh so much and be made of silver, copper, tin, &c. and have no more gold than a mere coat to cover it; but, in all those cases, it will be too big, and, by that means, lose too much weight in water; for sterling gold should be 17.793, or seventeen times and three-fourths as heavy as its bulk of water; and in order to try its purity by water, the hydrostatic balance has generally nippers and buckets to hold bodies to be weighed in water; but in this, as well as most

cases, a horse-hair will answer very well, being very strong, for the small space it occupies in the water. A loop in this hair will hold the guinea, and, being suspended on a light scale beam, it may be weighed in air, and found, probably, to weigh 129 grains. If, then, it be suspended in water, Fig. 25, its loss of weight may be seven grains and a quarter, by which, if 129 grains be divided, the quotient will be seventeen and three quarters, the specific gravity of the guinea, which is thus found to be a very good one.

5th. A suspected guinea may have full weight in air; it is immersed in water, and loses eight grains of its weight. This, then, is not sterling gold: for eight contained in 129 is only sixteen times; and it ought to have been seventeen and three quarters.

6th. Hence the alloy of such adulterated coin may be calculated pretty nearly by this method. Suppose a mass of metal, containing equal weights of gold and silver, was equal to the weight of two guineas, i. e. the gold was equal to 129 grains, and the silver part of the mass equal to 129 grains; then, together, the mass would weigh 258 grains. The gold (proved as above) would lose in water seven grains and a quarter, and the silver twelve grains and a half, together nineteen grains and three quarters; the 258 grains divided (as above) by nineteen and a quarter, would give thirteen as the specific gravity of the compound mass.

7th. If a guinea be adulterated with copper in a proportion of one to four, the mass may be considered as five grains. If five grains contain one grain of copper, what will 129 grains (the weight of the guinea) contain? It will contain 25.8 grains. The guinea must therefore contain 103.2 grains of gold, and 25.8 grains of copper. What then is the specific gravity of this guinea?

103.2 grains of gold would lose in water 5.5 grains,
25.8 grains of copper would lose in water 3. grains,

129 weight of the guinea, losing 8.5 grains

in water, would shew that 129 divided by 8.5, gives a quotient of about fifteen for the specific gravity of this guinea, instead of seventeen and three quarters; thus shewing its baseness.

8th. This baseness is pretty nearly calculated at the rate of 2.10 for every deficient grain; so that the last guinea would be really worth no more than about thirteen shillings, and yet the eye could not well detect the alloy. If the adulteration was with silver, each deficient grain should be valued at nearly four shillings. But as copper is the most general counterfeit, with a little silver mixed, about three allowed for every grain is near an average.

To find the specific gravity of bodies that are lighter than water, it must first be considered, that bodies rise in air, water, or any other fluid, not by their positive levity, but by the greater density of the medium in which they are immersed. This piece of cork rises in water, because it is bulk for bulk lighter than water: but I want to know how much. I therefore stick the cork on the hook of the small scale *a*, Fig. 25, and balancing it in the opposite scale, I find it weigh thirty grains. Now to force it into the water, I put weights in the scale *a*, 'till the cork is all immersed; the weights necessary to do this, I find to be 150 grains. This 150 grains, and the thirty, its aerial weight, together, is the weight of its bulk of water, viz. 180 grains. The specific gravity of the cork, therefore, is as the weight of its bulk of water to its weight in air; or (as in the heavy bodies), to divide its weight in air, by the weight

of its bulk of water, will give its specific gravity; thirty, therefore, divided by 180, will give 166, shewing the cork to be about ſix times lighter than water.

2d. I have two beams of deal timber to float down the river, containing seventy-five cubical feet: will this raft support a man to guide it? I take eight cubical inches of this wood, and stick it to the hook *a*, Fig. 25, and find it weighs, in air, four ounces: immersed in water, I find it requires half an ounce in the scale *a* to sink it; therefore four, its weight in air, divided by the weight of its bulk of water, 4.5, will give 88 for its specific gravity, so that it is not one-fifth lighter than its bulk of water. But a cubic foot of distilled water, or clear rain water, weighs, in air, 1000 ounces; and if eight cubical inches of wood weigh four ounces in air, 1728 (the number of cubic inches in a cubic foot) will weigh 864 ounces; which, if taken from 1000, will leave 136 ounces, that a cubic foot of this wood is lighter than a cubic foot of water. Hence, 75 times 136 would give 10,200 ounces, or 637 pounds, that the whole raft would be lighter than water, so that it would carry the man and his wife and children. This calculation must be admitted under certain modifications; wood soaked in water will grow heavier (therefore, experiments made on porous substances must be made as quick as poſſible); and water is lighter in hot than in cold weather, &c. &c.

To find the specific gravity of fluids. This might be easily done by weighing a given quantity of the fluid against an equal quantity of water: but the fact of a solid body losing so much of its weight in water, as is equal to the weight of its bulk of water, dictates a more elegant way of ascertaining what proportion any fluid bears to its weight of water. This solid is generally a conical piece of solid

glass, as Fig. 26, suspended from the scale *a*, Fig. 25, by a horse-hair: suppose its weight to be 1236 grains in air; and that it loses 412 in water; then 412 grains must be taken out of the weight scale to bring the balance even, when the glass is hanging in the water. The apparatus is now ready for business; and if the fluid to be estimated, be heavier than water, the solid glass will rise in it; if lighter, the glass will sink in it: so that the difference must be added or subtracted, as one or other is the case.

1st. The glass solid being now taken out of the water and immersed in brandy, it will be found to sink in it, and to require forty grains to bring the balance level: therefore the forty taken from 412, leaves 372; indicating, that the proportional weight of this brandy to water, is as 372 to 412: or, that it is about one-tenth lighter than water.

2d. The glass solid being now immersed in rectified spirit of wine, it balanced seventy-four grains more than in water; which being taken from the 412, leaves 338: the weight then of this spirit, in proportion to water, is as 338 to 412: or, if the weight in water, 412, be divided by seventy-four, the quotient will be 5.5, shewing the spirit to be rather less than one-sixth lighter than water. If water be estimated 1, the standard specific gravity of proof spirit is .93, to which the glass solid is easily adapted. But water and spirit forming a different penetration at different stages of their mixture, and also letting loose a little of their specific fire, at the instant they are mixed (and growing warm), the compound should stand some time before the trial.

3d. If it be required to find how much sea-water is heavier than

rain-water, immerse the glass solid in it, and it will be buoyed up so that ten grains will be required to bring the balance even; ten added to 412 will make sea-water to rain-water as 422 to 412. Or 412 divided by the additional weight, ten, will give forty-one; shewing, that it is rather more than the one-fortieth part heavier than rain-water, bulk for bulk.

On the Divers-bell.

THIS machine is founded on the principle, that air being a body, it excludes all other bodies from the place it possesses. If a bell-glass be pressed into water, with its mouth downward, the air in the glass will drive the water down before it, and very little will enter the bell. Availing himself of this principle, Dr. Halley constructed a bell of copper, three feet diameter a-top, five at bottom, and eight feet high; loaded at bottom with such a quantity of lead as to make the whole specifically heavier than its bulk of water. The divers were enlightened by a strong glass fixed in its top; and a stop-cock there, let out the heated air. This bell was lowered from the yard-arm of a ship, with two men in it, to the depth of ten fathoms. In their descent, they found the water rise in the bell; the air about them condensed; and thereby a disagreeable pressure formed on every part of their bodies, particularly at their ears, which seemed as if quills were thrust into them. They had light enough to see the pebbles at bottom, but it appeared red light, on every thing capable of reflecting it; the red part of light being the only one capable of forcing its way through resisting or muddy mediums. The air pressing through the pores of their skin, soon became as dense within their bodies as without, when the sense of pressure

ceased, and they found no difficulty in remaining at bottom several hours, where all was still and tranquil, though the surface was agitated with wind. Two barrels filled with air, were alternately sent down to them, and the heated contaminated air was let out, by the stop-cock, at the top of the bell. This bell, however, proved fatal to two men in the Bay of Dublin, by that contraction which ropes suffer in being wet: this caused the bell to turn round in its descent, and entangle the strings, by which the divers meant to ring bells, and indicate their wants to the people on board the ship, from whence they were lowered. Waiting too long for these signals, the bell was raised, and the divers were both found dead; but not drowned; they died like the unhappy people in the hole at Calcutta, by breathing contaminated air. (See Lecture on air.)

Being applied to, to give a design for a bell, to go down upon the same wreck, I recommended a conical tub of wood, three feet diameter at bottom, two and a half at top, and three feet high; so loaded with lead, at bottom, as just to sink of itself; with a small seat for the diver, Fig. 27: a bent metal tube was attached to the in and outside of the bell, as *a b c*, with a stop-cock at *a*; and a flexible leathern tube or hose to the other end at *c*: this tube terminated in a forcing air pump, fastened to the side of the ship; *d* is a solid piston, actuated by the lever *e*; upon the piston being drawn up, the air rushes in at the valve *g*, and fills the space *n*; on its descent, the valve *g* shuts, and the conical valve *o* opens, and lets the air be forced down the hose into the bell; this pump kept working, while the diver, by opening and shutting the stop-cock, is abundantly supplied with fresh air, and the vitiated part is forced out at the bottom of the bell. With this bell on his head, he can walk about several yards in a perpendicular posture, and having more easy access to pieces of

wreck than in a more cumbrous bell, can fasten ropes to them, and perform any business nearly as well as on dry land. The greatest part of the wreck saved from the rich ship Belgioso was taken up by means of this bell.

As the diver had plenty of air to spare, he thought a candle might be supported in the bell, and he could descend by night. He made the experiment, and presently found himself surrounded by fish, some very large, and many such as he had never seen before; they sported about the bell, and smelt at his legs as they hung in the water: this rather alarmed him, for he was not sure but some of the larger might take a fancy to him; he, therefore, rang his bell to be taken up, and the fish accompanied him, with much good nature, to the surface.

Mr. Smeaton's diving-bell at Ramsgate was of cast-iron, 50 cwt. so that it was heavy enough to sink of itself. Its shape was a parallelopiped, 4½ feet long, 3 wide, and 4½ feet high, so that two men could work under it, and could see, by four strong glass lights at top. It was supplied with air in a similar manner to the last.

Hydraulics.

As hydrostatics instruct us in the action, the motion, and pressure of fluids, so hydraulics apply these powers to mills, engines, pumps, pipes, canals, &c. When water is applied to mills, it is always found to act more powerfully by its weight than by its pressure; i. e. an overshot-wheel has always more power than

when the same quantity of water, and of the same perpendicular height, acts against, or under, the wheel. But where velocity is wanted more than great power, the undershot-wheel answers for carrying forge hammers, rolling hot iron, or any thing where dispatch is indispensable. On the overshot-wheel the water ought to fall about 5° over the perpendicular diameter to have its greatest power; and in the undershot-wheel, to strike the pedals at an angle of 45° below the horizontal diameter of the wheel, being directed to that place by a sluice inclining 45°; the water moving over a smooth bottom and sides, to have as little friction as possible. When water descends on a small overshot-wheel with greater rapidity than quantity, it is necessary to have a wide wheel, and an oblong aperture in the bottom of the penstock to deliver the water. The apertures that deliver water, if round, deliver it as the squares of their diameters; i. e. a hole twice the diameter of another will deliver four times the quantity of water in the same time, their perpendicular heights being also the same; and one, three times the diameter of another, will deliver nine times the quantity in the same time, &c. And as the velocity with which water spouts from an aperture either in the side or bottom of a reservoir, or vessel, is the same as the speed with which a body let fall in air would acquire in descending the height between the surface and the aperture; it follows, that water flows through holes agreeably to the odd numbers 1, 3, 5, 7, 9, &c. i. e. if into a tall pipe filled with water, I could make a puncture where I pleased, as, for instance, at the depth of one foot below the surface, and it discharged 36 cubic inches in a minute; if that hole was stopped up, and I make another of the same diameter three feet below that, the hole would discharge 72 cubic inches in a minute; if then I remove it five feet below that, the same hole would discharge 108 cubic inches in a minute, &c. being as the square

root of the height from the surface to the aperture, i. e. at the depth of four feet the hole discharged twice the quantity as at one foot; and at nine feet deep thrice the quantity, &c.; the water being kept at the same height in the tall pipe. A small allowance must be made for the friction and eddy in the apertures: but pipes will discharge much more water in the same time, than a thin hole of the same diameter, as may be seen by the following experiments, viz.

	Cubic inches.
A pipe of 4 inches long discharged per minute . .	12,279
——— 2 inches in length	12,188
——— 1½ inches long discharged	12,168

The water being kept to the same perpendicular height; so that we see the longest pipe discharged the most water: but where the aperture was the same, only a thin hole, the discharge was no more than in a proportion of 10 to 16, or about 7,674 cubic inches in a minute. This seems a little extraordinary, and is attempted to be accounted for in this way:—The easy mobility of water makes it press towards an aperture, where it is the least resisted, in a radiant form; as in the reservoir *a b*, Fig. 28, where the arrows point the direction of the fluid towards the aperture: now as the particles advance in opposite directions near the bottom, they form, by their collision, a little whirlpool at the place of their meeting, and pass through the hole in a circular thread, considerably smaller than the hole itself, as appears at *c*; by this means an aperture in a thin plate will not discharge so much water in a given time (and of the same height), by nearly one-third, as a pipe of two or three inches long, bored with the same instrument, and exactly of the same diameter: for the pipe prevents the eddy, and, therefore, receives the perpendicular weight less obstructed. The effect is much the

same in lateral pipes as in perpendicular ones, when the head of water is the same, as *d*, Fig. 28.

From these premises we learn, that the quantities of water discharged through different apertures, at different heights, are as the square of the diameter of the pipes, to the square roots of the perpendicular heights of the water above the pipes. This rule arises from the known qualities of the circle, that its area is as the square of its diameter, viz. a circle twice the diameter of another contains four times the space; and one three times the diameter of another, nine times the space, &c. So it is with the conducting pipes; one twice the diameter of another will discharge four times the water, when the head is the same height, &c. It has also been shewn that a pipe of equal bore with another, but four times as low, beneath the surface, will discharge twice the quantity of water in the same time; if nine times lower, three times the quantity; therefore, their discharge is as the square root of their depth.

Example. If a hole of 1 inch diameter, 4 feet beneath the surface, will, in 1 minute, discharge about 5,798 cubical inches of water; what quantity should be discharged by a pipe of 2 inches bore beneath a head of 9 feet?

As 1, the square of 1, multiplied by the square root of 4, viz. 2,

Is to 4 the square of 2 (the diameter of the lower pipe), multiplied by the square root of 9, viz. 3=12,

So is 5,798, the cubic inches of water,

To 34,788 cubic inches, that will be discharged by a pipe of 2 inches diameter, kept 9 feet below the surface one minute.

Or as 2 : 12 : : 5,798 : 34,788, &c.

If a pipe of two inches bore fill a cistern in an hour and an half; what bore should a pipe be that would fill it in half the time?

As less requires more in this question, it must be worked in reciprocal proportion.

As 90 minutes, the time in which it is now filled,

Is to 4 (the square of 2 inches),

So is 45 minutes (or half the time)

To 8, the square of the diameter of the pipe sought, and whose square root is 2.828 the diameter of the pipe required.

On the Syphon.

THIS is nothing more than a bent tube; and its use is that of decanting fluids out of wells, cisterns, barrels, &c. If the tube *a b*, Fig. 29, be filled with water, and then (with a finger on *a* and *b*) it be inverted, and its shorter leg immersed in *c*, full of water, the whole will rise over the vertex *d*, and be discharged at *b*. When the syphon is thus immersed in water, its outer leg is considered as from *d* to *b*; but its inner leg is only considered as from *d* to the surface of the water at *e*; for the water below *e*, is balanced by the water on the outside of that leg; so that the weight of water in the leg *d b* is so much heavier than that in the leg *d e*, that it will fall by its own gravity, and would leave a vacuum at *d*, if the pressure of the atmosphere on the surface *e* did not prevent it. Hence it is to the pressure or weight of the atmosphere that we are indebted for the action and use of the syphon.

This is easily proved by a syphon, whose legs are of an unequal length, as suppose the inner leg to be *a d*, and the outer leg only *d g*; in this case, the syphon will run till the water becomes level with

the end *g*, and there cease; the water hanging in the leg *d g* (a balance for that in *d c)*, until a bubble of air gets in at *g*, then that leg becomes lighter, and the water returns into the vessel.

2d. The syphon fountain, Fig. 30, also demonstrates the pressure of the air to be the cause why water seems to rise above its level in the syphon, but which is not so in reality; for water cannot be raised above its level by this instrument. In Fig. 30, *a* is the outer leg of the syphon, which passes through, and is fixed in, the brass cap of the glass cylinder *c*. The inner leg *b* also passes through the cap, and terminates above it in a capillary spouting pipe. If the cylinder be placed upright on the ground, a few spoonfuls of water may be poured into it at *d*; which will drive out an equal quantity of air through the leg *b*. If then the whole be inverted as in the figure, and the leg *b* immersed in water, the water in the cylinder will fall through the leg *a*, and driving the air before it, leave the air rarefied in the cylinder. The pressure of the air on the water in the cup *e* will then force the water into the cylinder in a beautiful jet.

3d. Tantalus's cup, Fig. 31, is another device to shew the action of the syphon. This cup is open at the bottom *c*, so that the longer leg of a syphon may be cemented into it, and make the cup capable of holding water; if water be then poured into it nearly to the bend of the syphon, the water will remain in it, as in a common cup; but if an apple be dropt into the water, it will begin to run out at the bottom, by the apple forcing the water over the bend of the syphon.

4th. In limestone mountains, caverns are very common; and

in their entrance large irregular rocks are generally jumbled together, so that it is not unnatural to suppose syphons may be formed amongst them, through which the water in the caverns must issue; wells formed from water, thus issuing, will ebb and flow, something like the sea, but by no means with the same regularity. As clouds are attracted by mountains, and also driven against their tops and sides by wind, mountainous countries are generally wet countries. But it cannot be supposed that *all* the water, thus falling on mountains, runs down their sides; by far the greatest part sinks into the chinks and pores of the ground and rocks, running in promiscuous channels, or percolating, through the gravel, till it finds a convenient place to break out; there it commences a spring, or a fountain, perhaps the head of a large river. For, dead and inanimate as our mother earth appears, we find her thus fraught with veins and arteries like the animal body, and we must actually prick one of those veins, before we can get water to supply a common pump. It is, therefore, the rain falling on the higher grounds, by which the lower are supplied with wells and springs. Rain falling on the mountain, Fig. 32, and percolating through the fissures *a a*, will drop into the cavern A, and in time fill it up to the level *b c*, when it will fall over the bend of the natural syphon *d c n*, and the whole be discharged at *n*: the fountain *n* will then remain dry till the cavern is again filled up to the level *b c*, &c. and hence ebb and flow.

5th. The distiller's crane, or syphon, Fig. 33, begins its action by the *vis inertiæ* of the fluid into which it is immersed. Let B be a barrel, and *n* its bung-hole. The syphon from *n* to *r* is about three feet long, and about one inch diameter; it has a stop-cock near its end, which must be shut, before the short end is put through

the bung-hole. If the barrel be full, one would not think the liquor would rise of itself over the bend *m*; but the cock being shut, the air in the crane will be condensed by the endeavour which the liquor within it will have to rise to its level: if then the cock be suddenly opened, the liquor will instantly spring over the bend *m*, and become all decanted.

On this principle, many years ago, I invented an useful, cheap, and simple machine to raise water above its level by its *vis inertiæ*, and the flexibility with which the particles of water slide over one another, for the purpose of making a ship pump herself. The first idea was that of a square close box, to be placed in the middle of the ship, reaching from her bottom, a little above the level of the water in the sea. In this box were triangular partitions, as Fig. 34; *a b* is the inside bottom of the ship; *c* is an opening into the first partition of the box; *d d d* are valves in each partition, opening upward. When the ship heels to the right, the bilge water rushes in at *c*, and opens the valve *d*; when the ship heels to the left, the valve *d* is shut, and the water (following the motion of the ship) rushes through the valve *e*, and so up to the top through the different partitions.

The objections to this mode of raising water, by the motion of the ship, were, that it occupied too much room in an important part of her; and the lowest valve would be liable to be choaked up by sand, coals, and other dirt: I also found that though in a model the momentum of the water was quite sufficient to open the valves, yet that much of that momentum was lost, by the short range the water had from one side of the box to the other. Why not therefore make that range the whole length of the ship, and leave the water

unconfined? Suppose, in Fig. 35, *a b* the length of the ship's keel, and that by placing it on the fulcrum *c*, that keel can be made to imitate the rolling, or pitching, of a ship. This model is an open box between *d* and *e*; but shut on the sides *e g* and *g b*. On *g b* is fixed a sloping pipe (conforming to the shape of the ship), having the valve *i* opening into it. The other end of the model being the same, needs no further description. The model being now held level on the fulcrum *c*, and nearly filled with water, if the end *b* is depressed, as in the figure, the water will rush into the box *e g b*, and pushing open the valve *i*, rise considerably high in the tube *i*. The valve will be instantly shut by the water now on its top, and on the end *a* being depressed, the water will rush into the opposite box, push open the valve *n*, and rise in the pipe *n*. This operation continued, the water will rise higher and higher in the pipes, till it is thrown out of the ends *o* and *p*, every returning motion of the ship. Why this should not answer at large, as well as in model, I know not. It has been shewn, explained, admired, and forgot.

The model to represent the hold of the ship was about three feet long, four inches wide, and four inches deep, as shaped Fig. 35; sixteen gills of water were put into it; and then it had a motion given it on its fulcrum *c*, so as to form an angle with the horizon of 20°, and each pitch took up one second of time. In every two pitches (after the pipes *o* and *p* were full), it discharged one-sixteenth of the bilge water at twice the height of its depth.

Another model for the same purpose, was two force-pumps, actuated by a globe of lead, as Fig. 36: this machine was to be placed on the bottom of the ship, and worked by her motion.

The pipes *o n* communicated with the bilge water, so that when the stern of the ship sunk beneath the horizontal level, as in the figure, the ball rolled down the lever L to *a*, and by its weight pressed down the piston *c*; forcing the water under it into the close box *d*. By the same motion the piston *s* was raised, and making a vacuum in the space *u*, the bilge water was pressed into it, through the valve *v*. Upon the stern of the vessel being depressed, the ball would roll down the channel L, and stop at *e*, by which the piston *s* would be forced down, and the water under it forced into the box *d*. When this box became full, the water would press open the valve *q*, and rise up the pipe *b* to the deck of the vessel.

I also spent some time and money in contriving and constructing a pendulum pump, to be actuated by the motion of a ship; but they all required more room than could be spared for them. If those hints, however, can stimulate to, or assist in, the prosecution of so desirable an addition to the perfections of a ship, I shall think these attempts not wholly lost to mankind.

Conducting Pipes.

WATER, like all other fluids, flows the easiest through, or over, itself: hence horizontal pipes of conduct should be larger than can be filled by the water that runs through them; so should ditches and drains; for the sides of pipes, and drains, that are filled with water, retard it by great friction. If horizontal pipes are filled from a reservoir, they discharge less in proportion to the distance they convey water; and that nearly in an inverse ratio to the square roots of that distance; i. e. if a pipe, 4 yards long, discharge 20 gallons in a minute, the same width of pipe, 9 yards

long, would discharge 13.3 gallons: for as 2 (square root of 4) is to 20 gallons, so is 3 (square root of 9) to 13.3.

It is a curious fact, that if the hole *c*, and the pipe *e*, Fig. 28, be bored with the same tool, the pipe will discharge nearly one-third more water than the hole in the same time. See Hydraulics.

Air will sometimes, in crooked tubes, form lodgments, that will stop flowing water, if its fall be inconsiderable. If I pour water into the funnel *a*, Fig. 37, the water will proceed to *b*, and there trickle down the part *b c*, leaving that space nearly filled with air, which will be imprisoned by water that will fill up the bottom at *c*. If more water be poured in at *a*, the column of air *b c* will force up the water to *d*, which also trickling down the declivity *d e*, will lodge between *e* and *n*, and prevent any water from making its way out at *o*. In pipes of consequence, sometimes a stop-cock is fixed at *b* and *d*, to let out the lodgments of air.

Of Pumps.

In the common sucking-pump, as it is called, water rises by the pressure of the atmosphere on the surface of the well. The principle may be more particularly seen by the glass model, Fig. 38, where *a* represents a ring of wood, or brass, with pliable leather fastened round it, to fit the cylinder A. Over the hole, in this ring, is a trap-door, or valve of metal, covered with leather, part of which often serves as a hinge for the valve to open and shut by. The handle and rod *r* end in a fork *s*, which, passing through the ring, or piston, is screwed fast to it on the underside.

Below this, and generally over a tube of a smaller bore as *z*, is another valve *v*, opening upward, which will suffer water to pass up, but not down. Now, when the piston *a* is pulled up by the handle (its valve being close), the column of air on its top is lifted, and a vacuum underneath takes place; to supply this, the air, in the lower part of the pump, presses into the vacuum, and hence the whole column of air *within* the pump becomes lighter than a similar column *without* the pump. By the superior pressure on the well, the water is forced into the pump, and through the valve *v*, which shutting, prevents its return. The piston being now forced down (as in the common act of pumping) through the the water (which opens the piston valve), the next stroke lifts the water to the spout of the pump, and making a vacuum underneath, at the same time a fresh quantity is forced through the lower valve, which, if very tight, will keep the water there; so that the pump, remaining always full, water is delivered at its spout, on the first motion of the handle. As this effect is produced by the pressure of the atmosphere, and as it is found that a column of water, of about thirty-two or thirty-three feet high, is equal in weight to a column of air of the same base of forty-five miles high, therefore, the piston *a* must always work below thirty-two feet from the surface of the water; perhaps if it never works more than twenty-eight feet above the water, it may be better, as the air varies much in its weight at different times.

Many attempts have been made to reduce the friction and wearing of this pump; metallic conical valves are great improvements. They are usefully formed as Fig. 39, which is a section of the whole piston: *o* is the conical valve, ground very even and smooth to fit its cavity in the piston *a a*; it is kept in its cavity by the weight *g*, and directed into it by the wire acting through *n*,

when lifted up by the water. The piston is leathered as usual, and the iron crane *s* goes through it, and is fastened by the screw nuts *r r*. *c* is the pump rod. Both the upper and lower valves are made in this form; if well made, they are water-tight, and never wear.

The manner in which this valve is applied, may be seen in the section of the pump, Fig. 40.

To lessen the friction of a piston, and prevent the injury it often suffers from gravel, sand, and other hard substances, a square trunk is used for the body of the pump, as Fig. 41, and a pyramidal piston, as Fig. 42. This pump, for temporary drainage, and to be worked by one man, is about four inches square within, and ten or twelve feet long, having a valve *d* opening into the trunk. The piston is generally made of strong horse leather, first cut out into goars, as Fig. 43, and when screwed together, appears as Fig. 42. The vertex of the pyramid is nailed to the end of the handle *c*; and the sides of the pyramid are sustained by small chains, or cords, fastened to the said handle: this precaution prevents the sides from rolling down, or giving way, when long soaked in water. This pump lies sloping on the bank of the pond, or pit, it is intended to drain; requires no fastening; and is easily removed: its piston, when thrust into water, gives way at its sides, and answers the purpose of a valve, letting water pass through it with the utmost ease; but on its being pulled up, the sides spread close to the sides of the trunk, driving up all the water before it, without more friction than is necessary to prevent the return of the water. This cheap and simple machine is peculiarly adapted for draining caissons, ponds, marl pits, quarries, &c.

To irrigate land in dry weather, without fatiguing the labourer, is of great importance in agriculture. A portable machine, of the shape of Fig. 44, will, I believe, answer this purpose very well. In most fields there are ditches or ponds, on the banks of which (as on a fulcrum) this bucket-lever will turn. *a b* are two inch boards, ten or twelve feet long, ten or twelve inches wide, and kept asunder by sides, water-tight, of two inches. On the upper board is fixed a staircase of battens, fixed across, as *o o*. Down this staircase a man walks to *b*, when his weight will sink the bucket *c* into the water, which will rise through the valve *d*. If he then walks up towards *a*, the bucket *e* will rise, by which its water will run under his feet and between the boards *a* and *b*, and be discharged at the hole *g* into a trough or channel, which will convey it away into the field. This machine may be doubled, as Fig. 45. *a b* are two inch boards, a foot wide, and twelve or fourteen feet long, separated by side-boards two inches wide, that make the trunk *x x*, leading into the buckets *c* and *e*. On the upper board is a triangular staircase, as in the figure, on which a man can walk up or down. At *o*, the fulcrum, is a partition in the trunk, that diverts the water into the hollow or tubulated fulcrum, *m*, Fig. 46. *d d* are two valves that let water into the buckets *c e*, but shutting prevent its return.

Two cubic feet, or about 15 gallons of water, being as much as a middle-sized man can lift, or counterbalance by his weight, on this lever, the buckets must be made in that proportion. Ditches and ponds being made in the waste parts of fields, may retain water enough in rainy weather to keep the land moist in the most dry. This machine may be conveyed on the shoulders of two men to any part of a farm.

Another method by which I have watered land was by means of a portable boat or punt; in the bottom of which was fixed an upright pump, communicating with the water in the pond, but preventing its entrance into the boat. This pump had a dished top, as *c c*, Fig. 47, stuck full of nails without heads; on this a wooden frustum, or a portion of a globe, was placed, having the mast *d* fixed in it; and under it (by a chain) the piston of the pump, made weighty enough to keep the mast upright when there was little wind. The sail on this mast kept always on the lee side of the mast, from what quarter soever the wind blew, which, nodding to the successive impulses of the wind, worked the pump, and forced the water over the bank of the ditch in the spout *g*. This little boat being moored by the stones *h* and *i* by way of anchors, kept the pump going whenever there was a wind, and watered its neighbourhood without trouble or attention.

Archimedes's screw-pump, Fig. 48, though one of the oldest methods of raising water, is not one of the worst, particularly for temporary drainage. Water rises in this hollow screw by endeavouring to fall. Its lower end being in the water, its upper may be raised so high, that the parts of the thread *c d* may lie nearly horizontally; yet not so much so, but that the declivity between *d* and *c* shall suffer the water to fall, and form lodgments in the lower parts of the thread, as *c c c*. This engine generally consists of three or four threads inclosed within a cylinder.

The Rope-pump. Fig. 49.

THIS singular pump consists of two or three hair ropes passing over a three-grooved pulley in the box *z* projecting over the well: they also pass under a pulley in the water, and are kept tight by a weight *e*. The upper pulley is put into swift motion by the wheel A. To the ascending parts of the ropes a quantity of water adheres, and is discharged with great violence in the box *z*. This adhesion is occasioned by the pressure of the atmosphere towards the ropes; as a considerable rarefaction of the air is made near the ropes by the swiftness of their motion. A man will raise about eight or nine gallons per minute out of a well near 100 feet deep with this pump.

The Forcing-pump.

THE principle of this pump may be seen in the model, Fig. 50, where *a* represents a solid piston, which, when drawn up, rarefies the air below it, and, of course, pressing lighter on the water within the pump than the pressure is on the well, that greater pressure forces up the water through the valve *c*, which (being made a little specifically heavier than the water) shuts, and prevents the return of the water. The piston *a* being now pressed down, the water above *c* is forced through the valve *d* into the air-vessel *g*. This vessel has a pipe *e* screwed tight into its top, that reaches nearly to the bottom of the air-vessel *g*, and is open at both ends: when the water, therefore, covers the lower end of this pipe, the air above it becomes a prisoner, and condensed, as

the water is forcing in, which, by its reaction on the surface of the water, forces that water through the pipe *e* with great velocity, and in a continued jet. It is on this principle that the extinguishing engine is formed, however different its construction may be; which is sometimes with two forcing pumps and an air-vessel between them: for the air-vessel is not only useful in preventing the bursting of the pipes, but in adding so considerably to the velocity of the water, that a raging fire is rather dashed out than extinguished by it; for so great is the repulsive force of fire, that water barely poured on dry combustibles would make them burn with greater fury, the water being carried off by the fire in the character of steam as fast as it is poured upon it. See No. 1, in the Table of Specific Gravities.

To make the piston of a sucking and forcing pump to act both upwards and downwards, and thereby produce a continued stream of water without the pulsations common to pumps, see No. 2, in the Plate of Specific Gravities. This piston is solid, and, when drawn up, rarefies the air within the pipe *c*, up which the water will flow, and through the valve *d*: on the descent of the piston, that water will be forced into the air-vessel *e*; and a vacuum will be made above the piston, which, communicating with the pipe *g*, will rarefy the air so much within that pipe, that the water will flow up it into *c*, and cover the piston. This water also will be forced up into the air-vessel by the ascent, or next stroke of the piston; so that water is raised both by the ascent and descent of the piston.

The most approved engine for extinguishing fire is one invented and made by Rowntree and Co. Surrey-road, Blackfriars. See Fig. 52, as a section of it. *a* is a semicylinder of cast-iron, having

a piston *c*, moved by the arms *b b*. This piston, or slider, is water-tight on all sides, as well as in the socket *g*. When the handle *b* is raised, the piston will be raised into the position *c*, and leave a vacuum in *a*: the water out of the trunk A will then rise up the pipe *n*, through the valve *o*, and flowing through the hole *z*, will fill the space *a*. On the next return of the handles *b b*, that water will be forced through the valve *s* into the conducting pipe, of which *u* is a section, and also into the air-vessel B, while a vacuum is made on the side of the piston *c*, and the same effect will take place on that side as on that of *a*; viz. the valve *r* will open, and the spaces *c r* will become filled with water, which, at the next stroke, will be forced through *v* into the conducting pipe *u*, and the air-vessel B; a vacuum being thus formed both before and behind the piston *c*, the water of course follows on both sides, and hence the semicylinder full of water is forced into the conducting pipe on every return of the handles *b b*. Twenty men may be employed to give this alternate motion to the machine, as may be seen in the elevation of it, Fig. 51, where two pipes may be employed, as C and D, and ten men to each of the handles *w x*. Dirt and gravel very frequently render other engines useless at the moment when they are most wanted: this is never so obstructed; for if any gets into the space *a c*, the first return of the piston *c* will throw them out through the openings *z y*; and should any dirt form a lodgment about the valves *o* or *r*, the screws *q q* can instantly give access to the inside.

Fig. 53, is a boat that can move against the stream or tide of a river; *a a a* are two sets of paddles, or oars, on one axle, *c*. These project before the stem of the boat, as in the plan, No. 2. On the axis there is a conical part *x*, on which a cord or rope is coiled three times round: the end of this cord is fastened to a stake by a

projecting side of the river, and, as it uncoils, hangs over the stern of the boat, as *m m m*. The conical part of the axle *x* obliges the cord to slide down it, so that the cord never coils round any other part of the axle. Three or four boats may move or follow one another on the cord *m*. There should be two cords of about 100 yards each, capable of being easily attached to, and detached from, each other; so that one might be carried forward up the river, and its end fastened, while the other was in use. This experiment was tried, and succeeded, on the Thames.

Another method, as No. 3, is to make a boat *walk* against the stream. The axle *c*, No. 2, is a crank, as *z*, No. 3; on this crank are looped the poles *q q*, with iron terminations to make them sink, and prevent their wearing. These poles walk under the boat, on the bottom of the river; and must be rather longer than the boat, to be applicable to the various depths of the river. This boat being long in proportion to its width, becomes a rudder, and always turns its head against the strongest and most rapid part of the stream; and, therefore, guides itself.

Fig. 54 is a boat machine for clearing the bottoms of rivers of gravel, mud, &c. It is moored over the bottom to be cleared, and is worked by the current of the river, by paddles on both sides of the boat, fixed at the ends of one axle, as in No. 2, Fig. 53. On this axle is the pinion *a*, working into the teeth of the wheel *b*: this wheel is supported on the fixed frame *g*, which is the side of a square hole that goes through the bottom of the boat, made tight to prevent water from getting into the habitable part of the boat. *c g x* is a frame of boards made to slide up and down through the hole in the bottom of the boat: in the bottom of this frame runs the roller *m*; over which, and the toothed roller *b*, goes the leathern

band *s s s*, having buckets *e e e* fixt in it at proper distances. This band is made to lengthen or shorten, as the river deepens, or grows shallow; and the weight of the frame *c g x* presses the buckets against the gravel, so that they may scrape it up, and rise full. When a bucket rises over the roller *b*, its mouth becomes inverted, and the gravel is thrown down into the body of the boat.

Boulton and Watts' Steam-engine, Fig. 55.

A. The boiler, about half filled with water.

B. The steam-pipe, that conveys the steam into the cylinder.

C. The door, where a person may enter to clean out the boiler.

D. The loaded, or safety valve; forced open by the steam when too strong; or to be opened by the handle *c*.

E. Feeding-pipe, from the warm-water cistern S.

F. Fire-door, opening to the fire under the boiler.

G. The ash-hole.

H. The cylinder, having a piston in it, on the end of the rod *d*, which works through the air-tight stuffing-box *o*.

I. Nozzles, where the steam is let out.

K. Plug-frame, to open and shut the valves in its rising and falling; thereby suffering the steam to pass to the condensing pump Q.

L. Beams that support the cylinder.

M. The exhaustion-pipe, that conveys the steam through the cold-water well O to the pump Q.

N. Injection-pipe, in the cold well, to throw in a little cold water into the exhaustion-pipe M.

O. The blowing-pipe, to let out air that might accumulate in the air-pump Q.

P. The barometer, to compare the strength of the steam with the pressure of the atmosphere.

Q. The air-pump, immersed in a well of cold water. When its piston ascends, by the chain Q, it draws the steam out of the cylinder, and condenses it by the coldness and the vacuum in the pump. The steam becoming water by this means, the piston descends into it, the piston valve is opened by the water (as in a common pump), and the next ascent of the piston forces that warm water through the box R up the pipe *r* into the cistern S (which pipe is cut short in the drawing, but it begins at the box R). This water supplies the boiler.

R. The box of the pipe *r*.

S. The cistern of ditto.

T. A forcing-pump, whose solid piston is forced down by the weights *s*, and the piston of the cylinder H drawn up. When the steam from the boiler forces down the piston of H, the piston in T rises, and rarefying the air in the inside or barrel of the pump, the pressure of the atmosphere on the surface of the well forces up the water as in a common pump: but by the descent of the piston in T, the water is forced through the pipe *x* to the place where it is wanted.

W. Is an air vessel to prevent the bursting of the pipes.

Z. The pipe to feed the condenser cistern O N Q.

Y. The great lever-beam.

This excellent machine is sometimes made to work by the pressure of steam both upward and downward; i. e. the steam can be made to press the piston up, as well as down. This adds considerably to the first expence, and the continued expence of fire.

Steam Engine, with the Cylinder in the Boiler.

IT is so important an object to keep the cylinder hot, that in the last engine the condensation of the steam is performed in a separate vessel, at a distance from the cylinder. To do this more effectually, I have had several engines made with the cylinder within the boiler, as Fig. 56.

A. The boiler, with the bottom part of the chimney passing through it.

B. The cylinder within the boiler, and fixed to its top; having holes all round that top to let in the steam.

C. Piston, the rod of which works through a collar of leathers or (stuffing-box) and is suspended from the great lever T. A joint in this rod, sliding in a groove, makes the stroke perpendicular.

D. A pipe from the cylinder B, communicating with the injection valve, and the cold water injection pipe I I, leading from the cold water cistern O.

E. Steam valve.

F. Injection ditto.

G. G. Eduction, or exhausting pipe, from the cylinder to the hot-well S.

H. Snifting clack, to let out air from the cylinder.

J. Pump for feeding the boiler.

K. Hot cistern.

L. Feed pipe, to supply the boiler with warm water from the hot-well K.

M. Waste pipe, to convey away the water when the hot cistern is too full.

N. The sucking and forcing pump, to raise water from a well, or river, to the cistern O.

O. Large cistern, reservoir, or penstock, from whence water can be turned on wheels, or made to supply towns, houses, &c.

P. Connecting rod from the beam T to the crank, which gives motion to the great fly.

Q. Q. Q. Plug-tree, for working the geer, i. e. to open and shut the valves, and work the hot pump.

R. Safety valve, to prevent the bursting of the boiler; if the steam be too strong, the valve opens and lets it out.

S. Hot-water well.

T. The great beam, or lever, connected with the piston C, the plug-tree, and the pumps.

These kind of machines approach nearer to the animation and powers of animal mechanism, than any yet invented by man.

Fig. 15.

Fig. 29.

Fig. 30.

Fig. 31.

Fig. 33.

Fig. 3.

Fig. 34.

Fig. 37.

Fig. 32. N°. 1.

Fig. 32. N°. 2.

Fig. 43.

Fig. 41.

Fig. 1.

Fig. 42.

Barlow sculp.t

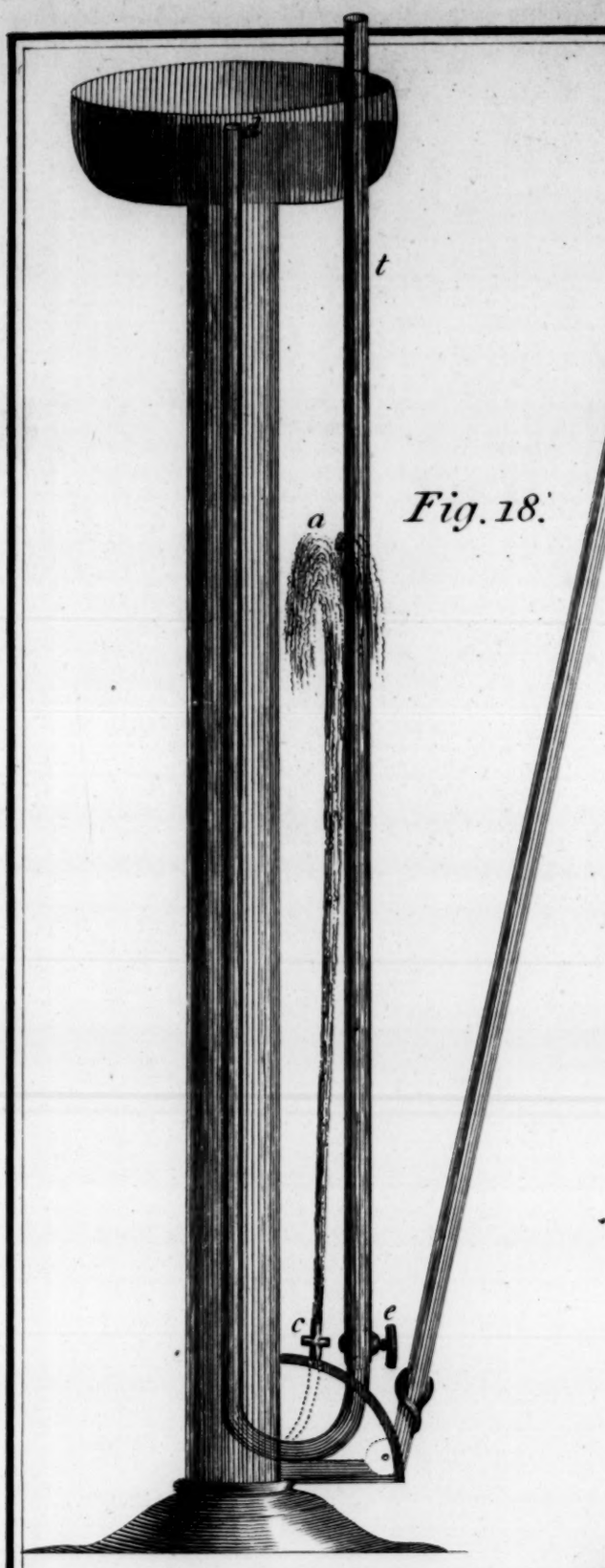


Fig. 18.



Fig. 20.



Fig. 19.

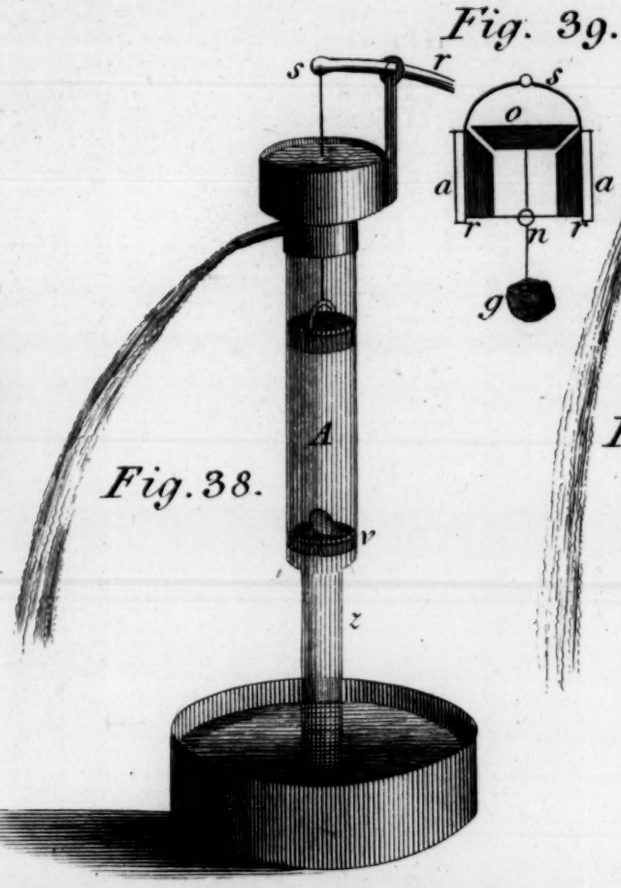


Fig. 38.

Fig. 39.

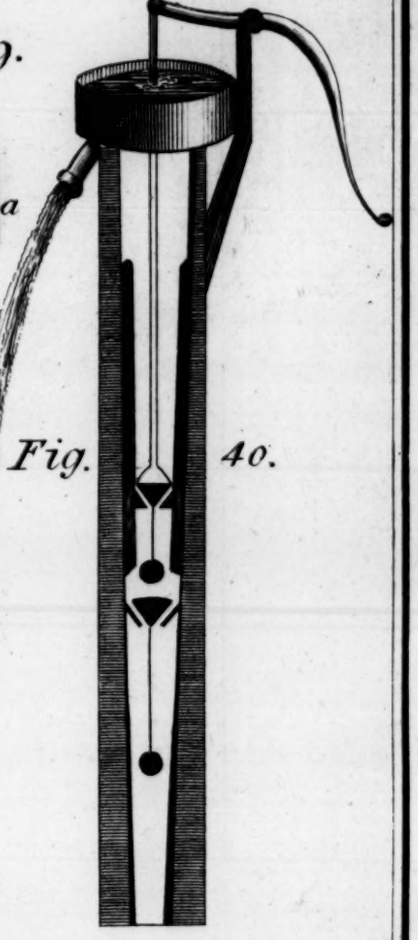


Fig. 40.



Fig. 11.

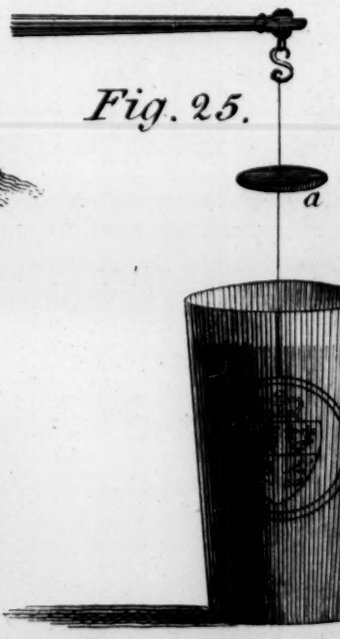


Fig. 25.

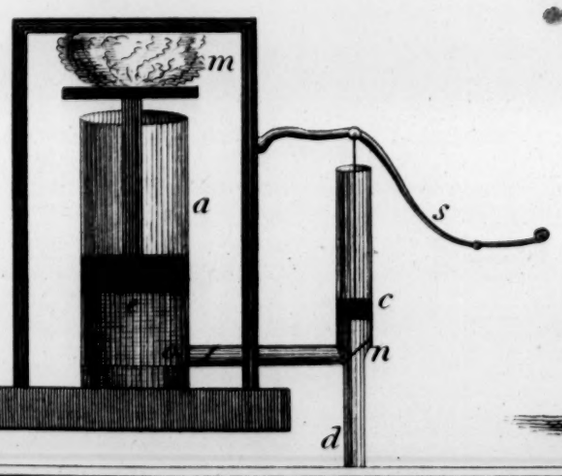


Fig. 10.

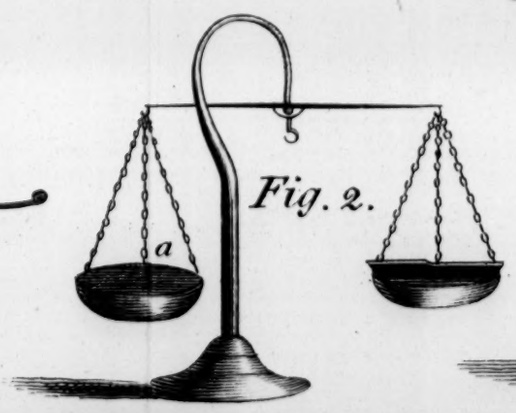


Fig. 2.

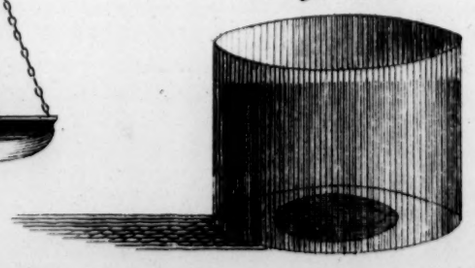


Fig. 23.

Barlow sculp.

Fig. 17.

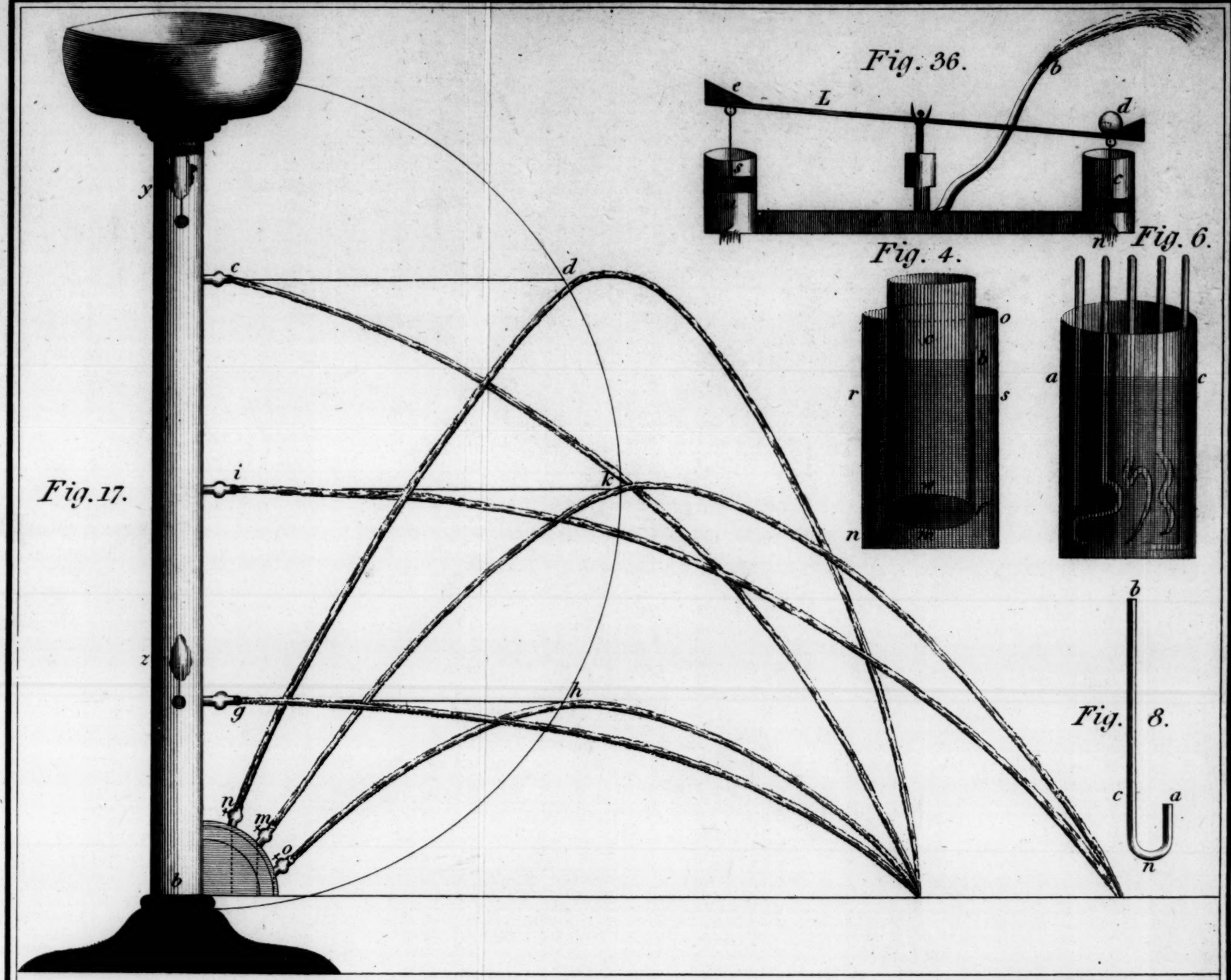


Fig. 36.

Fig. 4.

Fig. 6.

Fig. 8.

Fig. 5.



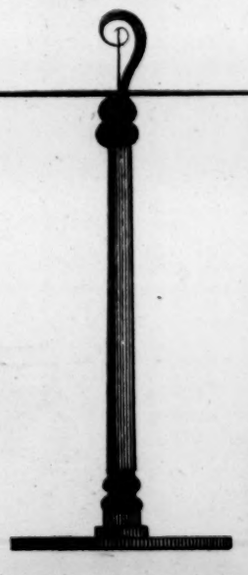
Fig. 9.



Fig. 7.



Fig. 12.



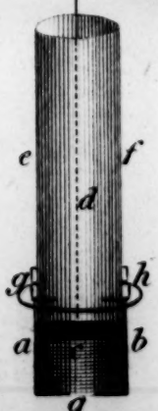


Fig. 12. No 2.



Fig. 13.

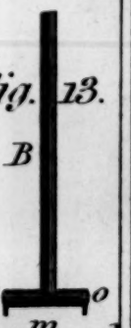
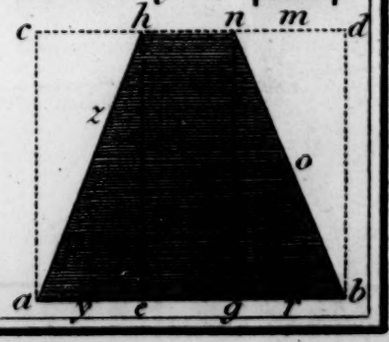


Fig. 14.



Barlow sculp.t

Pl IV.



Fig 22

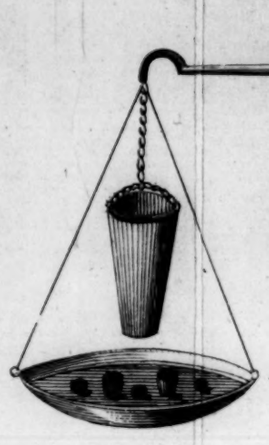
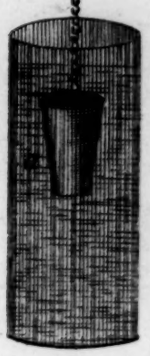


Fig. 24.



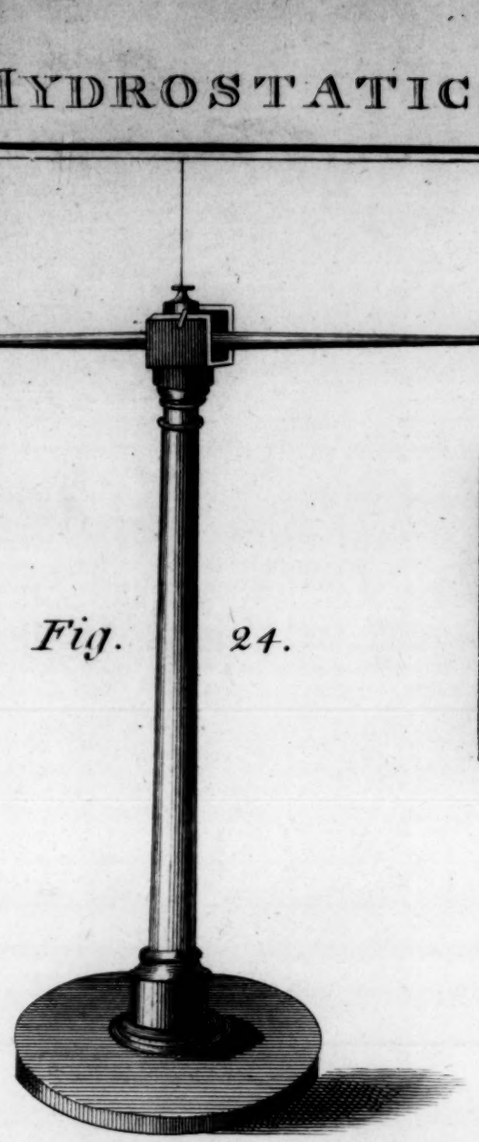


Fig. 26.

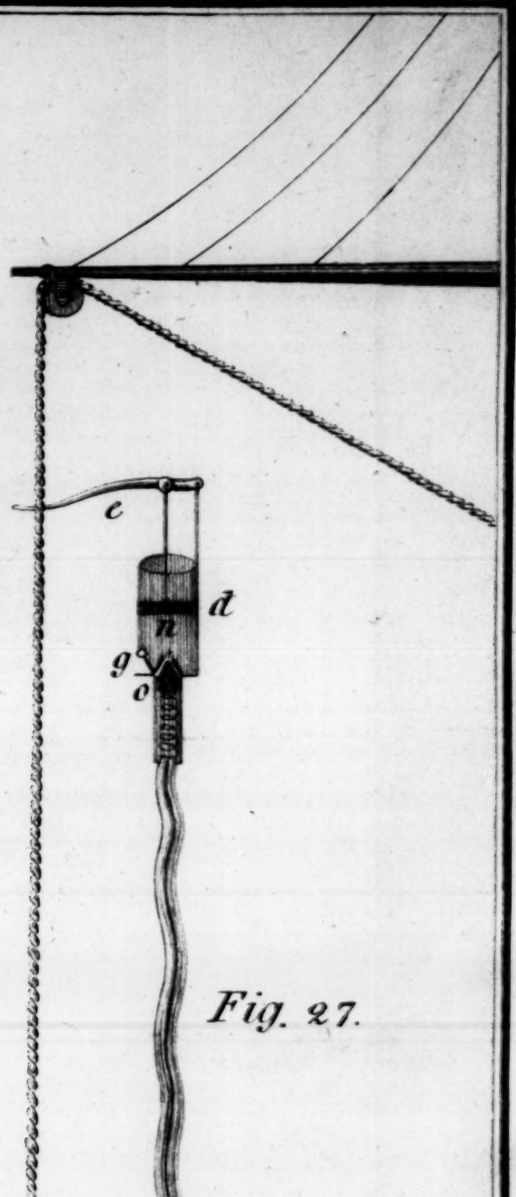


Fig. 27.

Fig 21

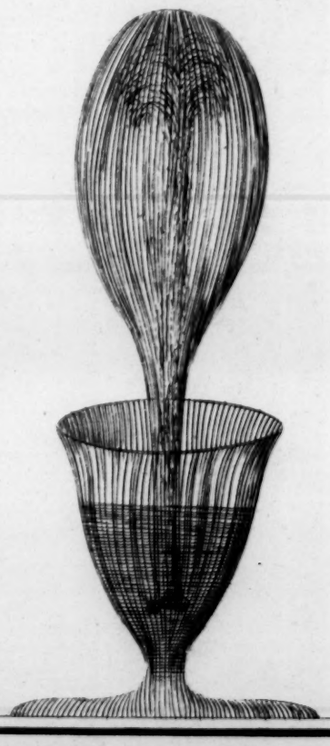
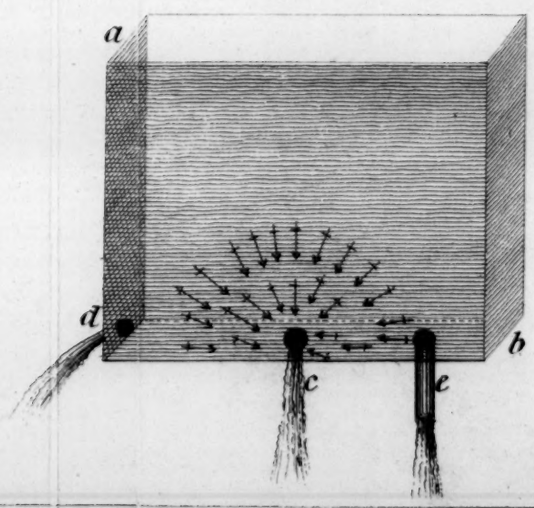


Fig. 28.



Barlow sculp.

Fig. 45.

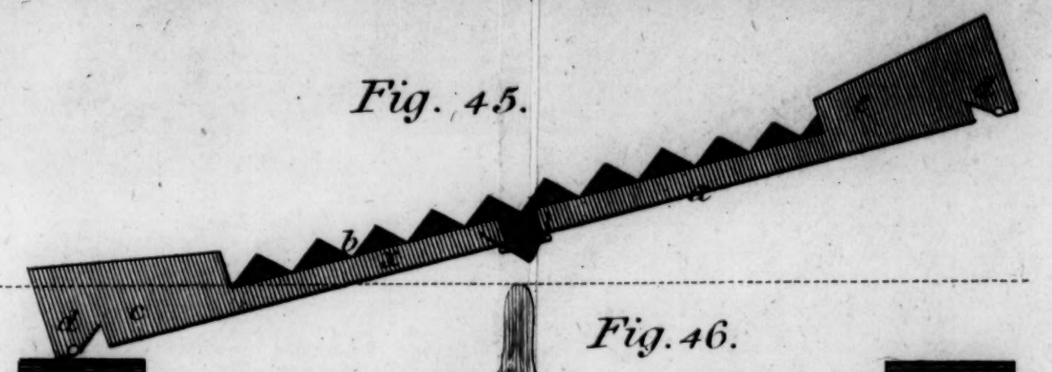


Fig. 46.

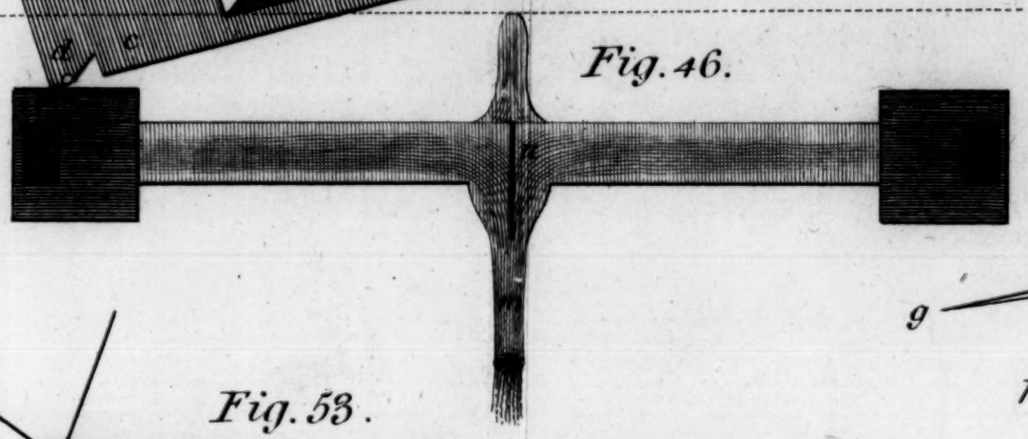


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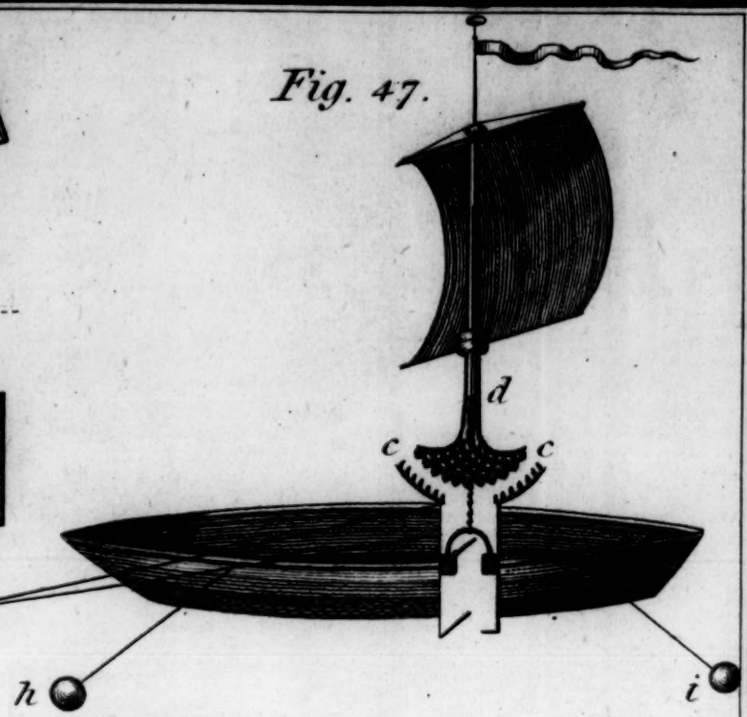


Fig. 53.

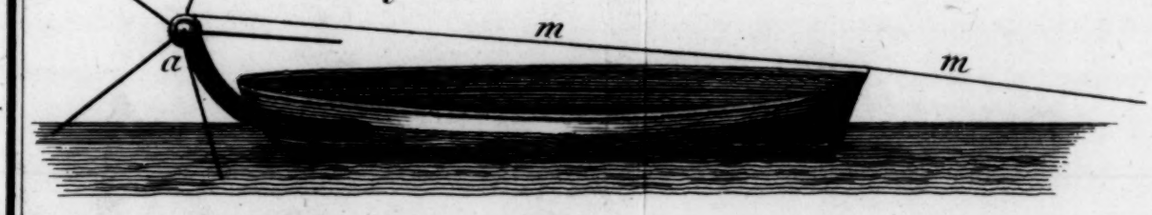
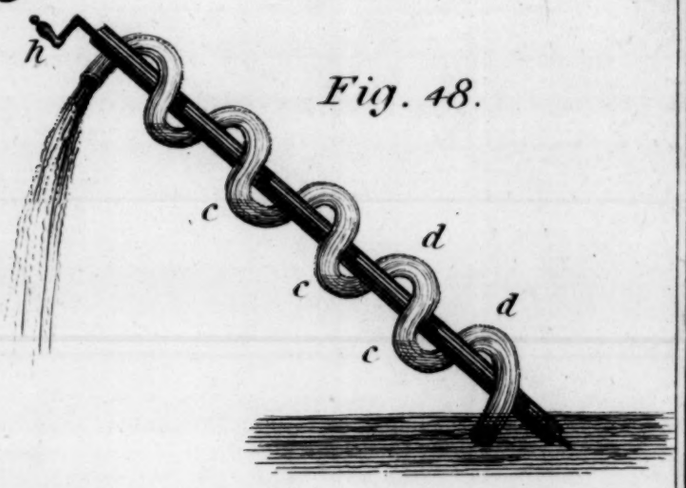
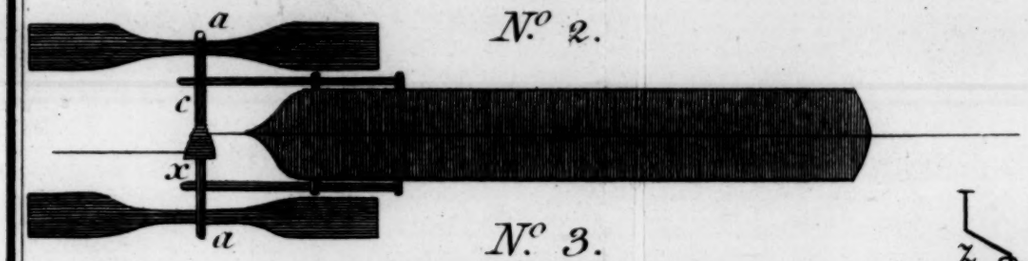


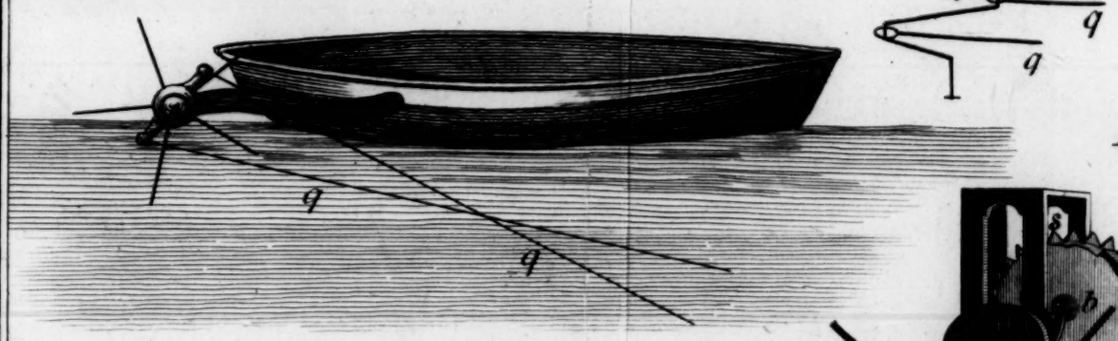
Fig. 48.



N.o 2.



N.o 3.



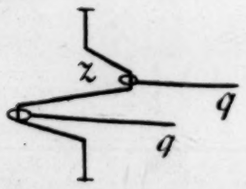
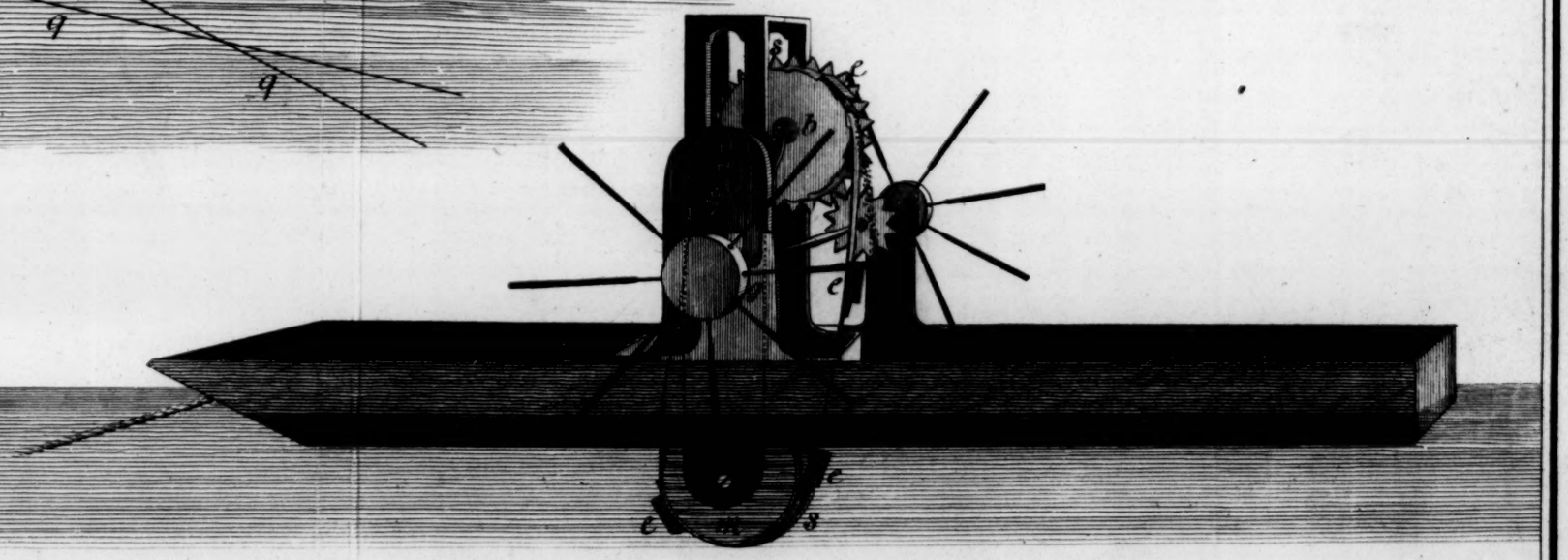


Fig. 54. page 318.



Barlow sculp.

Fig. 49.

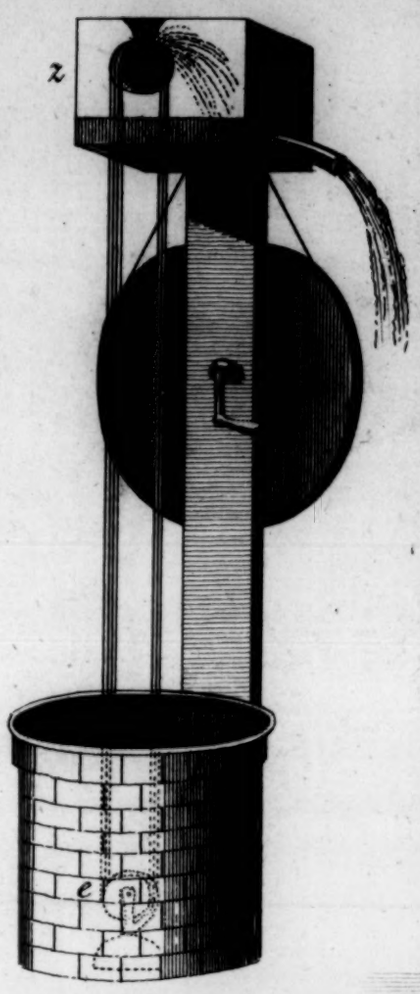


Fig. 50.

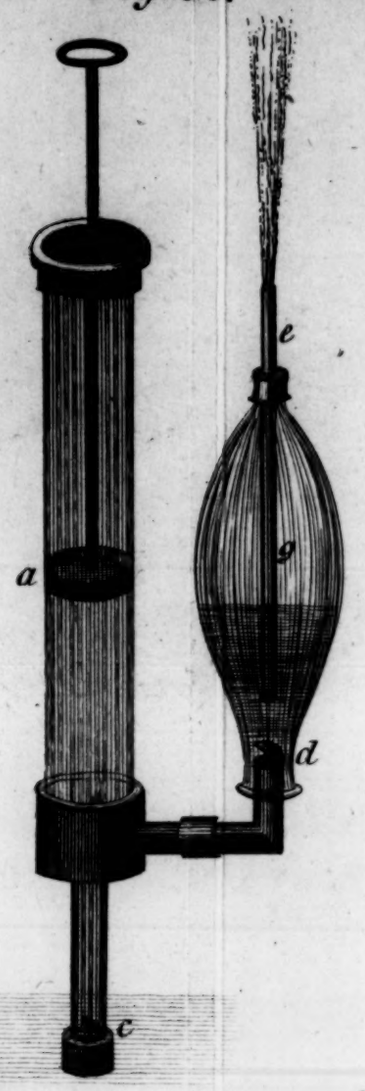


Fig. 38.

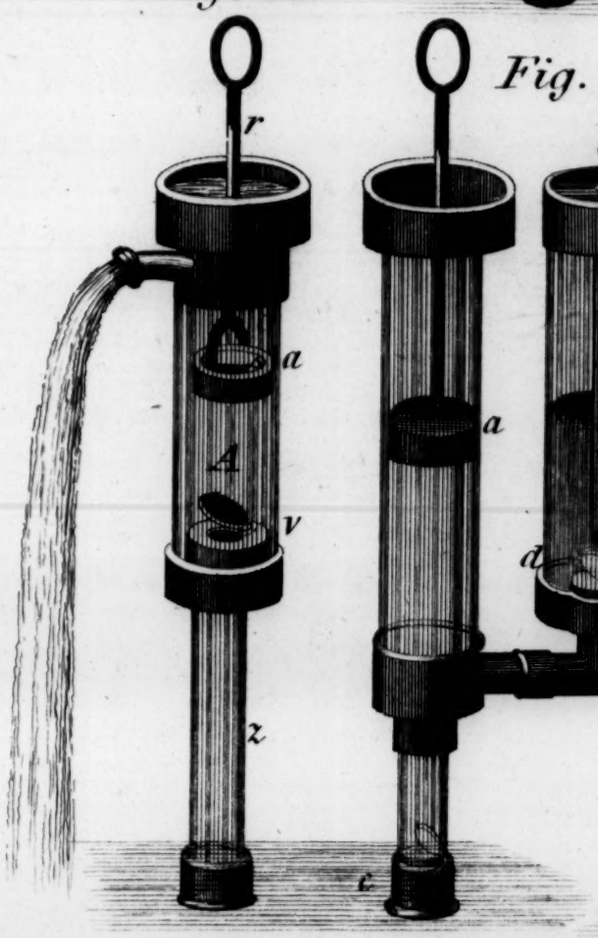


Fig. 50.

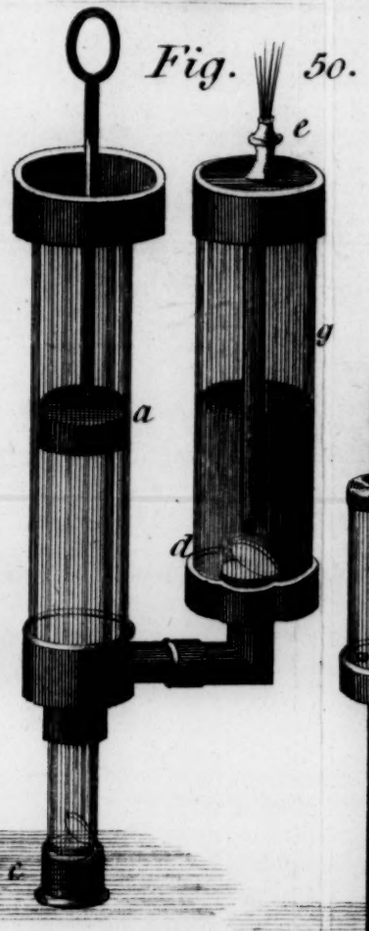
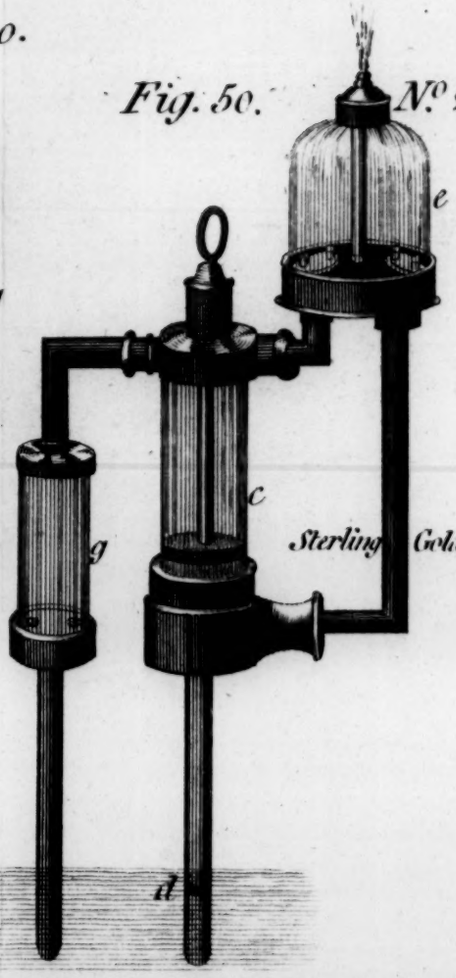


Fig. 50. N.o 2.



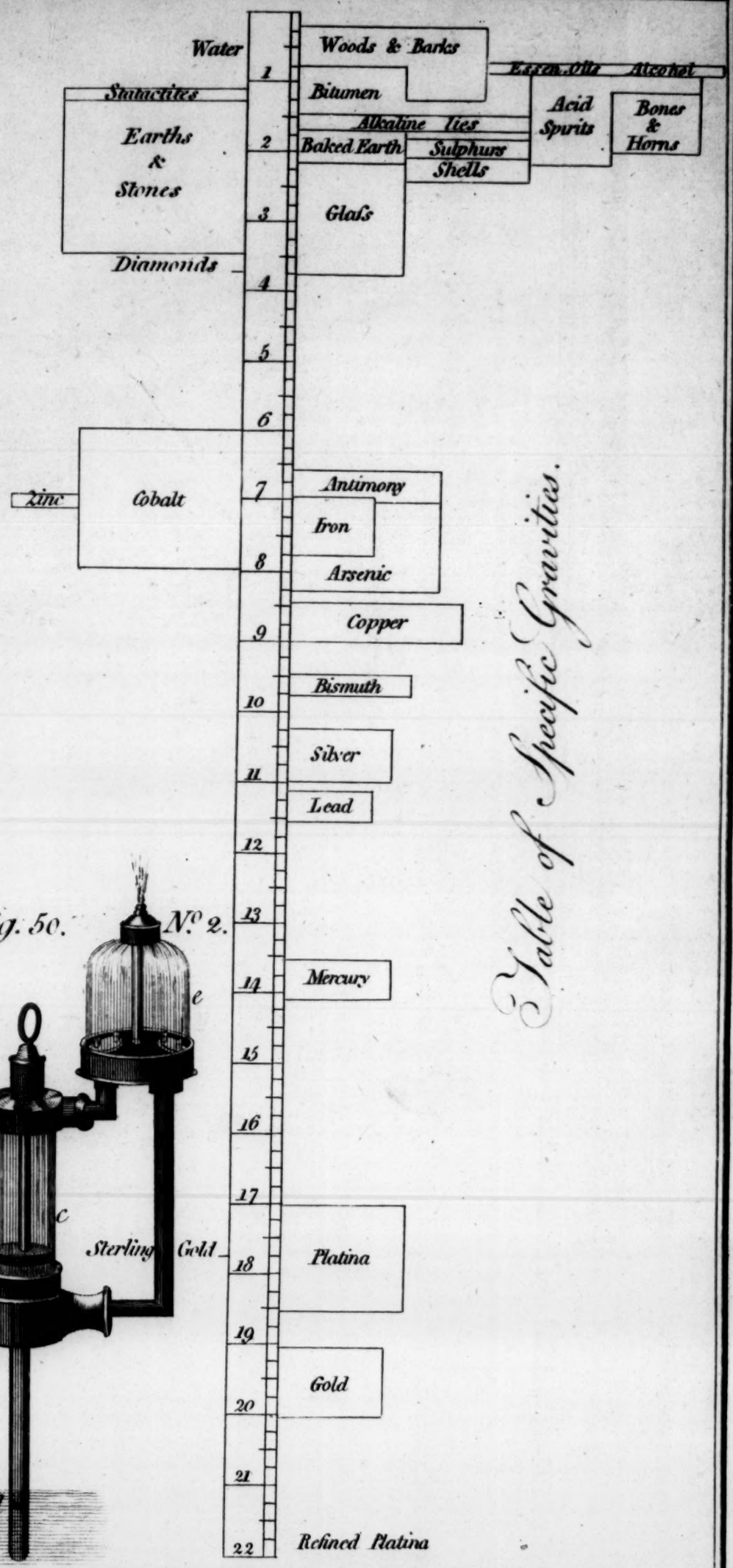
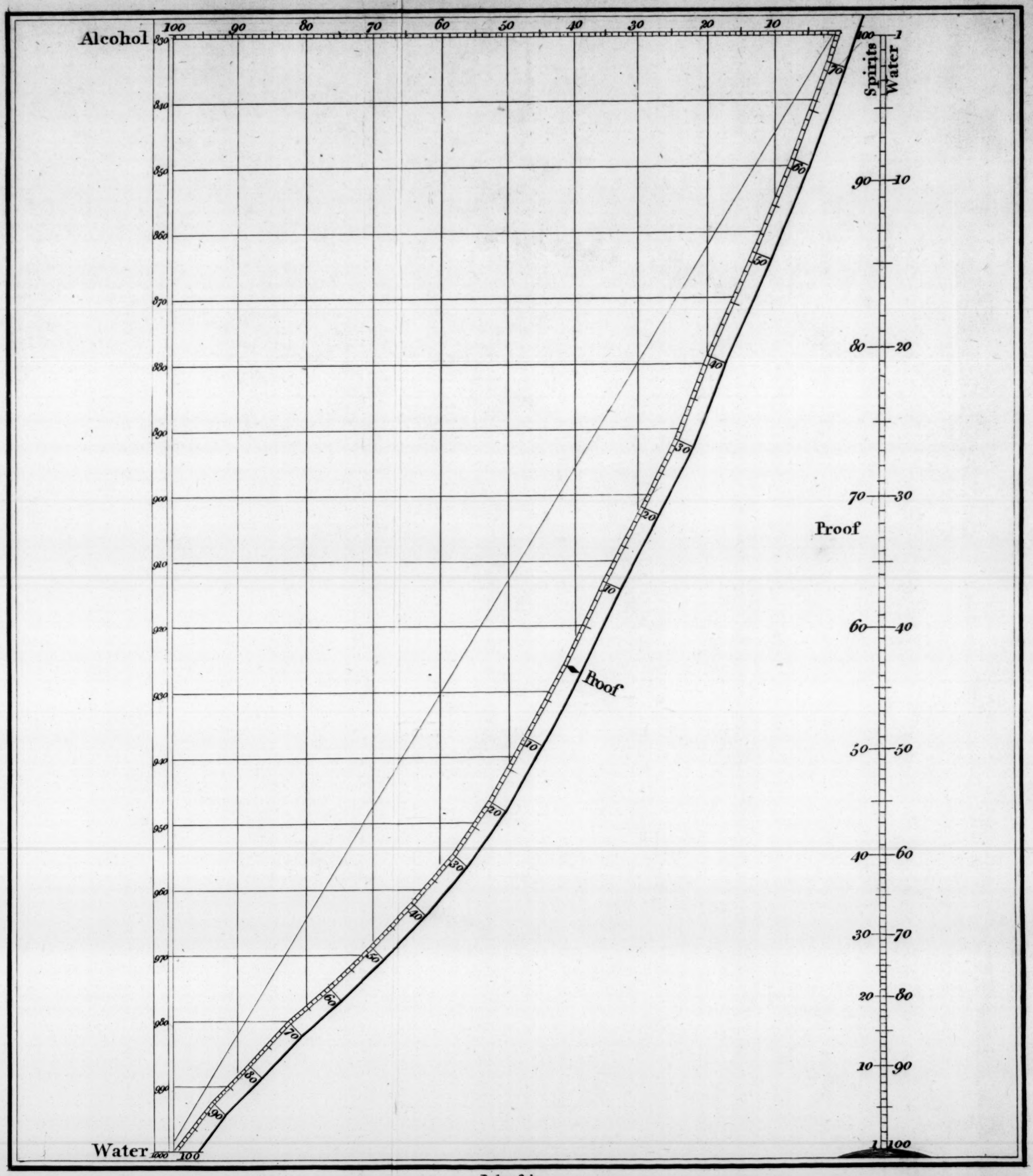


Table of Specific Gravities.

Barlow Sculp.

HYDROMETRICAL TABLE.



Barlow Sculp.

EXTINGUISHING ENGINE.

Fig. 52.

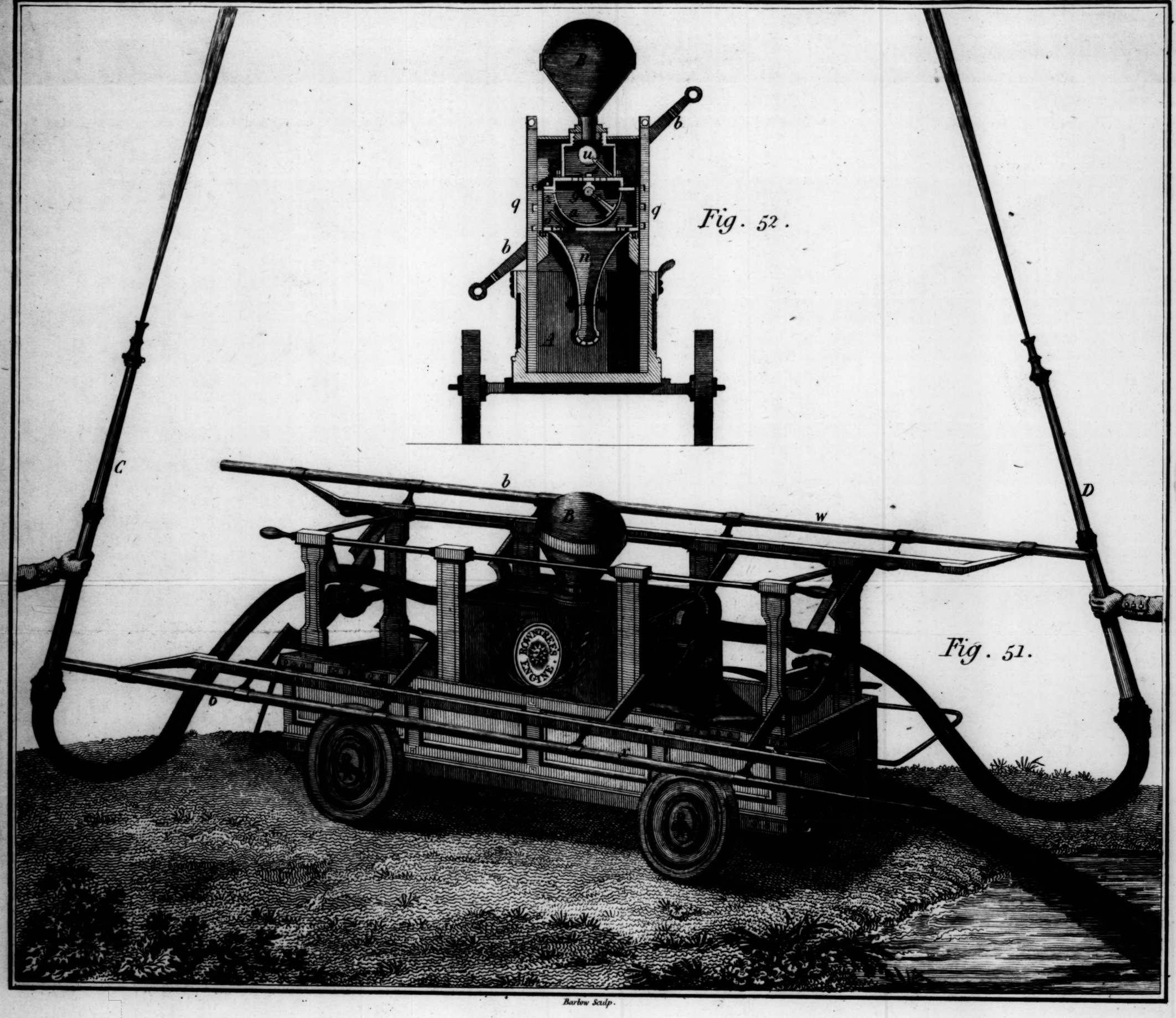
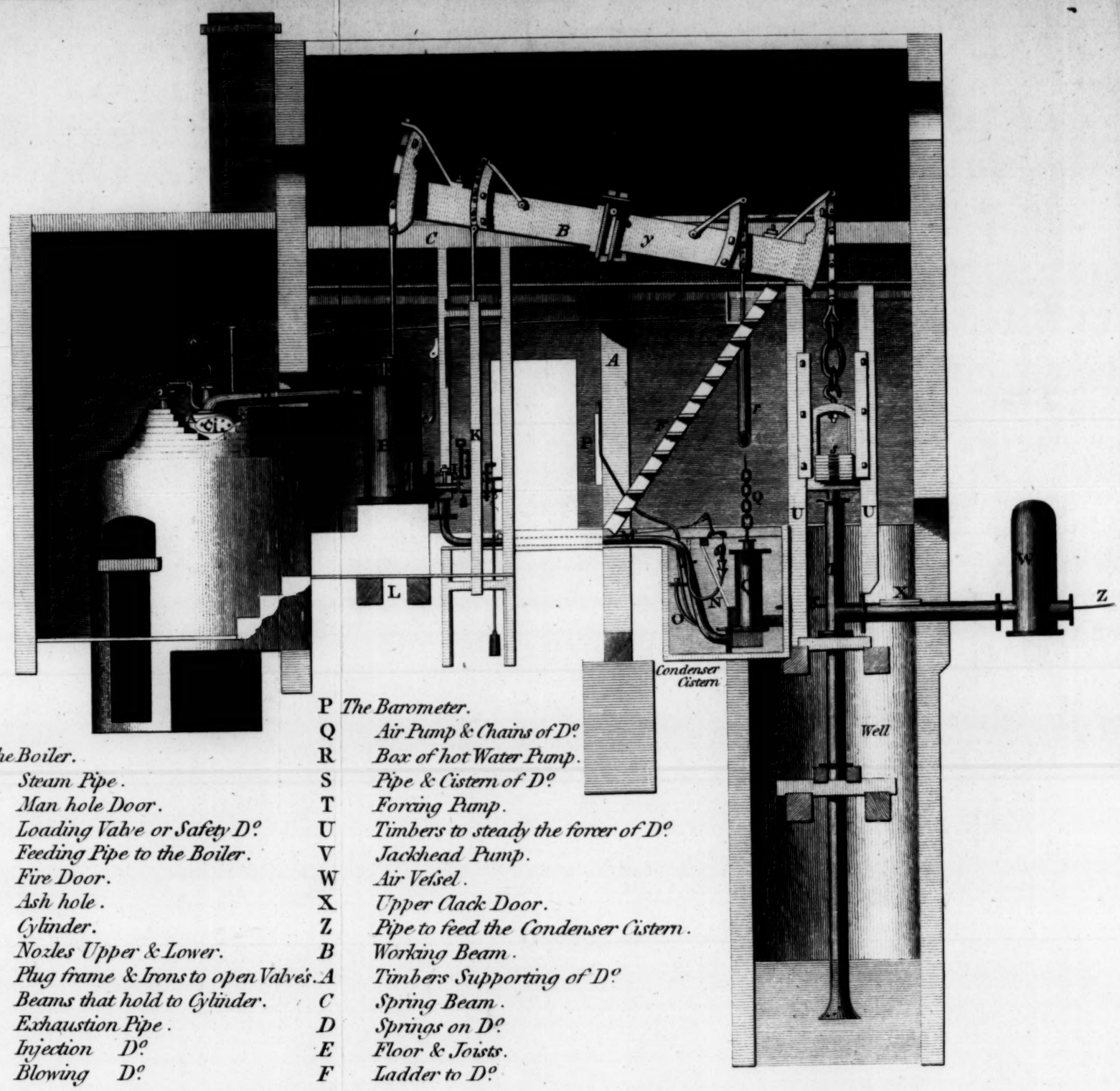


Fig. 51.

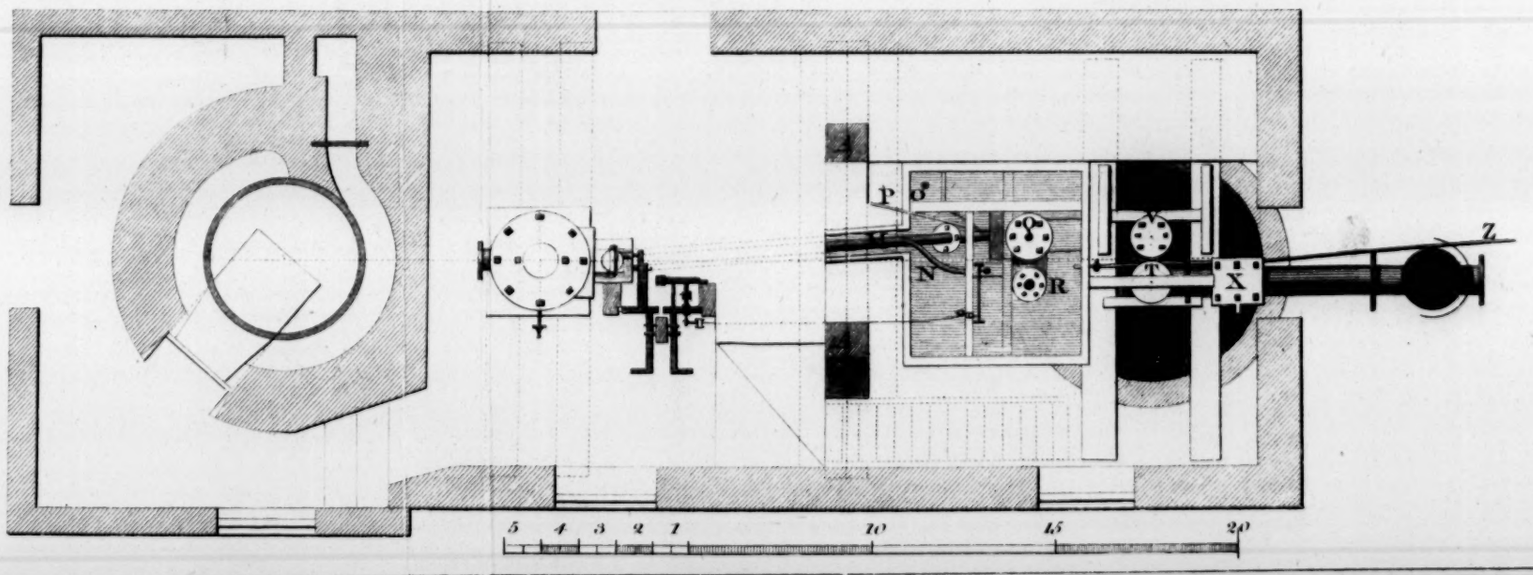
Barlow Sculp.

Boulton & Co.s new invented Patent Fire Engine.



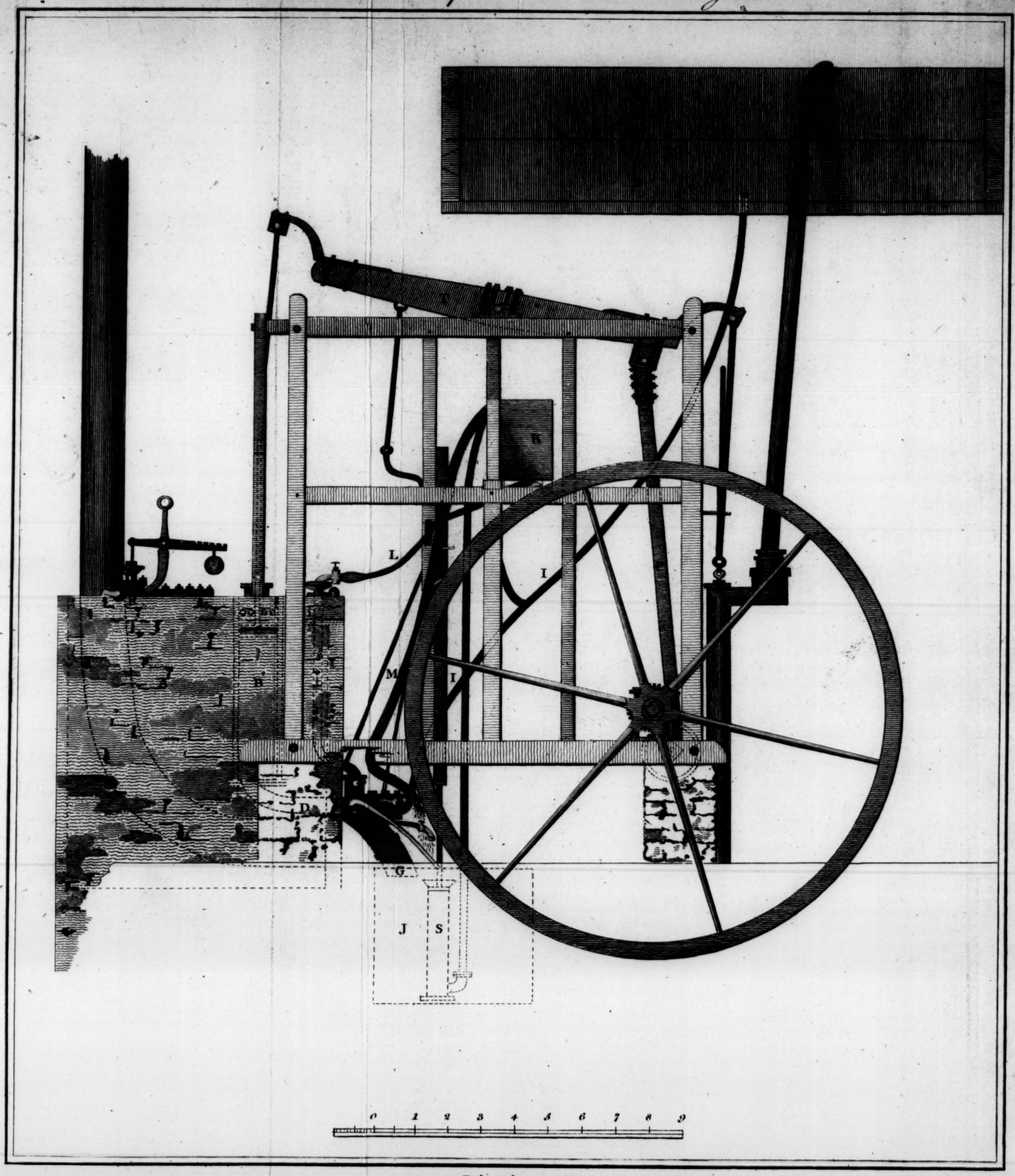
A *The Boiler.*
B *Steam Pipe.*
C *Man hole Door.*
D *Loading Valve or Safety Dº.*
E *Feeding Pipe to the Boiler.*
F *Fire Door.*
G *Ash hole.*
H *Cylinder.*
I *Nozles Upper & Lower.*
K *Plug frame & Irons to open Valves.*
L *Beams that hold to Cylinder.*
M *Exhaustion Pipe.*
N *Injection Dº.*
O *Blowing Dº.*

P *The Barometer.*
Q *Air Pump & Chains of Dº.*
R *Box of hot Water Pump.*
S *Pipe & Cistern of Dº.*
T *Forcing Pump.*
U *Timbers to steady the forcer of Dº.*
V *Jackhead Pump.*
W *Air Vessel.*
X *Upper Clack Door.*
Z *Pipe to feed the Condenser Cistern.*
B *Working Beam.*
A *Timbers Supporting of Dº.*
C *Spring Beam.*
D *Springs on Dº.*
E *Floor & Joists.*
F *Ladder to Dº.*



Barlow sculp.

Mr. Walker's improved Steam Engine.



Barlow sculp.

LECTURE VII.

ELECTRICITY.

THE history of philosophy affords us nothing more early known than electricity, though it is generally conceived to be the latest discovery that has been made in the world of enquiry; for Theophrastus expressly mentions it 300 years before the Christian era; but all that was known of it, in that, and many succeeding ages, was little more than that amber, wax, glass, and such substances being rubbed, had the property of attracting feathers, straws, and such light bodies. It is not till within this last century, that we have been enabled to know that it is diffused, more or less, through every kind of matter on which we can make any experiments; and, that it is, perhaps, one of the most powerful and important agents in nature! What this wonderful matter is, has engaged the thoughts, and pens, of the first philosophers of our times. It was called Electricity, because it was first detected in amber, whose Greek name is ηλεκτρον, from ηλεκτωρ, *Sol*; a derivation that happily meets my ideas respecting the origin of this fluid; for I conceive it to be a child of the sun; an equatorial emanation from that luminary; and the first source of light and fire. Not to multiply causes, but to make one cause account for as many effects as possible, I humbly conceive this subtil matter to be the genuine principle of light and fire: which, uniting with the finest particles of terrestrial matter in the atmosphere, becomes light; and

chemically combining with the grosser parts, fire. My reasons for this hypothesis are, their similarity, in numberless instances, respecting *appearances*, *motion*, *power*, and other effects. As to *appearance*, impressions made on the optic nerve, by solar light, and electricity, are precisely the same. The electric spark is commonly white like solar light; and when looked at, through a prism, will be found to exhibit the seven primitive colours of red, orange, yellow, green, blue, indigo, and violet, like a ray of the sun's light decomposed in a dark room by a prism. When difficulties arise in the transmission of electricity, through dubious, or imperfect conductors, then none but red rays can struggle through: and the spark is red; the sun looks thus, when his rays are stopt by a fog, and none but the powerful red can force its way through it; so do distant lamps seen through a smoky atmosphere in large cities. For if a round piece of smooth deal be covered, as *a b*, Fig. 1, with tin foil, and three or four inches left bare, from *b* to *c*; and the part from *c* to *d*, be covered; if the end *a* be held to an electrified conductor, a red spark will dart from *b* to *c*, over the uncovered ill-conducting wood. 2d. If a glass tube, of two inches diameter, and three feet long, have brass caps at *a* and *b*, Fig. 2, to make it air-tight; and, by means of a screw and a valve, it can be fixed to an air-pump and be exhausted of its air. If, when it is about half exhausted, the end *b* be addressed to an electrified conductor, red flames will pass through the tube: exhausted a little more, and all the colours will pass separately and promiscuously through the tube. But when nearly exhausted to a vacuum, they will then go through altogether so mixed, as to appear white. Is not this similar to the difficulties, that solar light manifests in making its way through mediums of different resisting powers? 3d. Bodies much involved in light become, in general, coloured, volatile, and inflammable: and bodies the most coloured, are the

best conductors of fire: electricity impresses the colours of the rain-bow, on polished metals, and makes even gold volatile. Are not these conformities favourable to the doctrine, that fire, light, and electricity, are but modifications of one and the same principle? 4th. When the eye has been some time shut up in the dark, and comes suddenly in the face of a clear sun, if the eye be then closed, and kept so for some time, a strong white impression will continue on the optic nerve for several seconds; the spectrum will then turn violet; after some time blue, then green, and so on regularly in the order of the prismatic colours. The first impression is white, because that is the natural colour of the sun's light; or it may be called the result of a mixture of the seven primitive colours: the violet being the weakest, it becomes repelled from the optic nerve first, and producing an irritability in its exit, induces a temporary sensation of that colour. The blue succeeds, &c. If the electrical battery, Fig. 3, be charged, and the knob *a*, of the discharging rod, be first put to the knob *c*, (which communicates with the inside coating of all the jars) and the wire *d*, (which communicates with their outside coating) have one end in the water *m*: if then the knob *z* touch the water, a vivid stream of electrical light will pass over the surface of the water, from *z* to *d*, making (in the dark) the same impression on the optic nerve, as the sun, which at first will be white, then violet, then blue, &c. Many other similarities, in respect to *appearance*, might be brought forward; but we now proceed to compare the

Motion of light and electricity; both of which appear so inconceivably swift, as to seem incalculable! By the eclipses of Jupiter's satellites, and the aberration of light from the fixed stars (see Optics), we can estimate the time in which light travels from the sun to the earth. Not that I conceive the individual particles pro-

jected from the sun reach the eye in eight minutes; I conceive all space to be always filled with either active or latent electricity or light; which, in the latter, case, is put into motion by *that* immediately projected from the sun. For light and electricity being repulsive of themselves, if the particle *a*, Fig. 4, be just projected from the sun *s*, it will repulse the particle *b*; the particle *b* will repulse *c*, &c. &c. and in eight minutes and twelve seconds, the particle *i*, will strike an eye on the earth. Electricity is likewise progressive in common experiments. Beccaria electrified one end of a wire of some hundred yards in length; he had small pieces of leaf gold placed near both its ends; when the excitation began, he saw the pieces of leaf gold attracted at the electrified end, some instants sooner than those at the other end. Are not electrical effects, therefore, propagated through conducting substances, by putting their inherent and latent electricity into motion, like the progression of light? 2d. When a wire is heated red-hot by an electric battery, the red begins at the end next the positive conductor; proving that its motion is progressive. It is true, that electrical circuits have been made from the in to the outside of the Leyden jars of seven, eight, and nine miles in length, through the crooked parts of the New River, the Thames, and also by a wire suspended on a park wall of nine miles in circuit, which seemed to be so instantaneous, that no estimate could be made of the time it took up. I have electrified two regiments of soldiers, consisting of eighteen hundred men, who apparently all received the shock in the same instant. But a shock is like the discharge of a bullet through the air, which drives its particles into a mass, and, therefore, we cannot judge of electric motion by its shocks, but by its progress through very long conducting substances. 3d. If feathers be stuck in each end of a long conductor, those next the exciting cylinder, will betray signs of

electricity first; shewing that its motion through the conductor is progressive.

The similitude of light and electricity, in respect to *power* or force, is particularly striking. Light brought to a focus on opaque bodies, by large lenses or mirrors, produces the most intense heat (for what is light at the surface of a burning glass, is fire at its focus). It will melt metals; vitrify stones; reduce ores, and oxyds to metals; boil gold; fire ships, &c. Fire does the same; and so will Electricity. If the battery, Fig. 3, be charged, and a small iron wire be tied to the hook *e*, and the other end to the knob *z*, of the discharging rod, and then, by the glass handle *f*, the knob *a*, be brought to touch *c*, the discharge will pass through the wire, and melt it. If the experiment be performed in the dark, the molten iron will fly about the room like red hot bullets. If the battery be very large (suppose sixty-four jars of about a gallon each, properly coated) the wire will lose all metallic appearance, and be reduced to a calx, or oxyd, and fly about like little flakes of ash-coloured cotton.

2d. Let pieces of leaf gold be put at the tenth of an inch from one another, between two thin slips of window-glass on the ivory table *a*, Fig. 5, and be held fast to the table by the rods *c* and *b*, turning on the stiff joints *e* and *d*, and insulated by the glass legs *g g*. If the battery, Fig. 3, be charged, and a wire or chain from the hook *e* join the rod *c*, Fig. 5, and the knob *z* of the discharging rod touch the rod *b*, at the same time that its other knob *a* touches knob *c* of the battery, the discharge will pass between the glass slips, break them in its passage, melt the gold leaf, and enamel or incorporate it in the pieces of broken glass! If a small weight be placed on the glass slips, the experiment will succeed better.

3d. By the electric shock, borax and glass have been melted, and metals revived from their calces or oxyds, as zinc and quicksilver; and it is shewn that the same things can be done by fire and by light. Are not these further proofs of their identity?

Of the other similar *effects* of light and electricity numberless instances may be produced. Metals are calcined by light in the focus of a large burning lens, as Fig. 6. So are metals by large shocks of electricity; particularly quicksilver: if a crooked tube be half filled with quicksilver, and inverted in two glass vessels filled with that metal as *a* and *z*, Fig. 6, and a wire communicating with the outside coating of a large electric jar, be hooked to the wire *c*; if then a communication be made (with the discharging rod) between the wire *d*, and the inside coating of the jar, a shock will pass through the quicksilver, and the space *e*. When the shock has been several times repeated, the air in the space *b e g*, will be found considerably diminished, and little red globules will appear on the surface of the quicksilver. If the shocks are continued, the pure part of the air will all disappear, and become a part of the red calx or oxyd, agreeably to the manner of all calcinations.

2d. Vegetables thrive in light, and die in darkness: so insulated beds of flowers, and all germination, frequently electrified, have had their growth accelerated; as well as the hatching of eggs. Both light and electricity change vegetable blue juices red; both produce flame; expand fluids; precipitate lime from lime water; and promote the growth of vegetables.

3d. Electric shocks, sent through a sword blade, excite the same order of prismatic colours on the steel, as is made on it by

different degrees of heat; whether that heat is produced by culinary fire or light.

4th. Spirit of wine, smoke of a candle just put out, gunpowder, powder of colophony, resin, &c. ignite with the smallest spark of electricity, even when conducted by a piece of ice; because their latent fire is copious, and not fettered as culinary fire in general is by aqueous, saline, or terrestrial particles, which make its disengagement slow and inactive. Whereas electric fire drives into, and excites the natural fire inherent in bodies.

5th. Canton's phosphorus (made of calcined oyster-shells), if hermetically sealed in a glass, and exposed to any coloured light, such as may pass through a ruby, a sapphire, &c. may be seen to return or reflect the same light when instantly exposed in the dark. So when the same phosphorus is held near an electric explosion, whatever is the colour of the explosion, that colour will be seen emitting for several minutes in the dark from the phosphorus. Hence letters, the planets, and many other devices painted with the white of an egg, and the pounded phosphorus strewed upon it, will continue luminous in the dark (after being held near an electric explosion) for several minutes; and continue to have that effect for years, if kept very dry.

6th. Ashes, coals, and other burnt bodies, revive to combustibility when exposed to light, and then uniting in the composition of vegetables, become again sapid and inflammable. So if alkaline air (which is totally uninflammable) be inclosed in the tube *g e h*, Fig. 6, over quicksilver, and electrical shocks be sent through it for some time, the air will increase in bulk, and become completely inflammable. Does not an insulated combustible burn with

greater vigour and brilliancy when electrified during the time of its combustion?

7th. Fire and light expand all bodies with which they unite, or come in contact with. So if a tall glass jar be half filled with water, as Fig. 8, and inverted in a vessel, having the wire and knob *c* standing in it; and then another knob and wire, acting through the collar of leathers *d*, be placed about an inch from the other knob, an explosion from a large jar, and darting from *z* to *c*, will so swell the air as to depress the water in the jar.

It has been said that electricity cannot be excited by the rubbing of two conducting substances together, nor by the friction of two non-conducting substances; this is not true; for, if two pieces of broken china be rubbed gently together, one piece will be in a positive, and the other in a negative state; as may be proved by holding insulated small flaxen threads near them, as Fig. 7, *a b* being glass. But if the edges of the pieces of china be struck briskly together, they will produce sparks of fire, but no electricity: for if the threads are held near them, no signs of electricity will appear. 2d. Two glass tubes rubbed briskly together produce a vivid purple light in the dark, and a strong phosphoric smell; but no attraction or repulsion, as may be proved by the above threads*: but if two pieces of plate glass be warmed and gently rubbed together, the one will be found in a positive, the other in a negative state, by the above test. 3d. Air and glass are both non-conductors, yet if warmed glass be blown on by a pair of bellows, it will

* Yet friction universally produces electricity; two non-electrics rubbed together have their electricity disturbed, but instantly restored, and two electrics rubbed together betray no signs for the same reason: so when effects are not sensible, it is only because electricity is lost as soon as produced.

betray signs of electricity, so will amber. May not gentle friction, therefore, exhibit fire in the pure character of electricity? and when more violence is used, call it forth (mixt with terrestrial matter) as common fire?

These analogies, I hope, prove the identity of light, fire, and electricity; and if light and fire have been proved in another lecture to be derived from the sun, I trust we may also consider him as the parent of electricity. Yet still there are great differences between the action of fire and electricity. Ordinary fire or light will not give the electric shock, nor produce lightning; neither will ordinary air discharge a bullet till it is condensed; yet still it is air.

Why is there more thunder and lightning in summer than in winter? in hot than in cold climates? Is it not because the sun's rays are more direct upon us at that season, and that a greater quantity of electricity falls on that part of the earth and its atmosphere? May not that abundance sometimes so supersaturate the upper regions of the air (which from its rarity is a conductor, and of course a receiver of electricity), that it shall make violent efforts to get through the non-conducting lower regions of the atmosphere, and produce thunder and lightning? Are not those concentrations of electricity called thunder-bolts favourable to this opinion? For, that accumulated lightning does often assume the appearance of a ball of fire is beyond all doubt; and such have even been produced by artificial electricity. I conceive solar light to be in a more elementary state in the character of the electric fluid, than it is in either ordinary fire or light; for in our experiments upon both we always find them entangled with terrestrial matter: could we refine them from that matter, I presume to think the result would be electricity. May not this ethereal matter be pure electricity coming from the

sun, but mixt and so far contaminated in travelling through our atmosphere, that *in the air it shall only be light, and in the earth fire?* That this fire shall be culinary when called forth from the earth by ordinary *combustion*, and electric when called forth by *friction?* The atmosphere is generally in a positive state, except when it is in a state of disease by thunder and lightning; it is then positive and negative by swift gradation, indicative of the perturbed state of the air, which cannot conduct the lightning swift enough into the earth; or, the earth's attraction, for it cannot be satisfied without a negative exertion in its favour, to help it through the air. Do we not often see condensed lightning fall from the atmosphere like a ball, and roll along the dry earth before it can make its way into it? and do we not often see it in the character, of a meteor fly obliquely the length of a nation before it finds the sea, or ground sufficiently moist for its admittance? and may not comets themselves be a condensation of opposing light, from different suns, concentrated by opposition, and impelled into the stream of the most powerful light? As calculation has failed in regard to those wonderful bodies, a conjecture I hope may be pardoned.

SECTION II.

On Electrical Machines.

HAVING thus endeavoured to establish what I conceive Electricity to be, I must now try to explain the best modes of its excitation, and making those experiments already mentioned. An electrical machine is now so common, that I shall only mention the two forms I think the best. A cylinder of well annealed glass, about

eighteen inches long in the belly, and fourteen diameter, is a good size. The caps should be of hard wood, as round and smooth as possible, and of a piece with centres on which the cylinder turns: to one of these centres the handle *a* should be fixed, Fig. 9. The two conductors, *b* and *c*, are of copper or tin, very smooth, round, and without points or edges, of about eighteen inches long, and eight inches diameter. To the negative conductor *b*, must be fixed an elastic cushion of red leather, stuffed evenly with curled hair, of about ten inches long, and fixed so as to lie flat to the cylinder: on its under side must be sewed a piece of the above leather ten inches wide, and five inches long; and at the same place a piece of black Persian silk ten inches wide, and sixteen inches long, that will reach over the cylinder, as *d*; to the prime conductor *c*, must be attached a row of eight points, each about the length of common pins, whose points must be as near the glass cylinder as possible, without touching: both ends of the cylinder, as well as the two conductors, must be supported on solid glass pillars. The pillar *g* should be fastened on a piece of board that could slide in a groove, and be fixed by a wooden screw to the board that supports the whole machine: this is to press the cushion more or less to the cylinder. On the part of the silk that touches the cylinder, under the cushion, should be spread a little amalgam*, and the machine is then ready for experiments.

Another machine, of greater power, is made of a round plate of thick looking-glass, Fig. 9, No. 2. This plate turns on an axis *a*, supported by the mahogany frame *c c c*, by the handle *g*. The rubbers

* Melted zinc poured on an equal weight of quicksilver, and stirred together, makes a very good amalgam. A better is said to be by melting two ounces of tin, and one ounce of zinc, and pouring these on three ounces of quicksilver in a wooden box well chalked within; being stirred, they unite into a hard mass, which must be well pounded and sifted through cambric, and then mixt with as much hog's lard as will make it spread.

are of red leather stuffed with curled hair, and nailed to thin slips of wood *d d*, one on each side of the glass, and made to press the glass very close by the screws, *x x*. To these rubbers are attached oil'd-silk curtains *z z*, on both sides of the glass. The conductor *w w w* is of brass, and fixed to the frame *c c c*, by the glass supporter *q*, which insulates the conductor *w*, and terminates in the two knobs *s s*; into these knobs are screwed small cylinders of brass, with a number of points that nearly touch the glass, and receive the electric matter from it: they cannot be seen in the drawing, being behind the curtains. For exciting positive electricity in all kinds of weather, and situations, this is the most powerful and convenient machine that has yet been invented. Before we begin to use the machine, it may be necessary to lay down a few electrical axioms. 1st. All natural bodies are divided into two classes, *electrics* and *conductors*. *Electric* substances, such as glass, air, silk, &c. will not transmit electricity: *conductors*, such as metals, water, &c. do transmit it. 2d. Conducting and non-conducting substances rubbed together, appear to be both electrified, but possessed of different electricities; as when glass is rubbed with a piece of leather, the glass will be found in a positive, plus, or vitreous state; the leather in the negative, minus, or resinous state. 3d. By this we are not to understand that there are two electricities, though called by so many opposite names. Electricity and lightning *are one fluid*, probably an emanation from the sun's atmosphere; and by positive and negative is only meant *more* or *less* of one and the same fluid. 4th. Bodies possessed of the same electricity, whether positive or negative, repel each other: possessed of different electricities they attract each other. 5th. When bodies too heavy to be drawn by electrical attraction, come near an electrified body, they instantly become possessed of an electricity, contrary to that of the electrified body. 6th. When electricity enters a point, it appears a star in

the dark: when it issues from a point, it is like a brush. In the last case it often flames from the rubber of the machine, into the air, when not carried off fast enough by the point of the conductor. 7th. An electric atmosphere not only repels another electric atmosphere, but it will also repel the electric matter in the substance of any body it approaches; and, without mixing with it, force it to a further part of that body.

If a chain be hung to the negative conductor *b*, Fig. 9, reaching to a moist floor, wall, or any conducting matter communicating with the earth, and the cylinder be turned, sparks may be taken by the knuckle, or any piece of metal, from the prime conductor *c*, at two, three, or more inches distance.

That electricity after penetrating through the atmosphere, and approaching the earth, has its affinities like other matter, and becomes a latent principle in bodies till called into activity by frictions or heat, is more than probable, from the readiness with which some bodies part with it, and the tenacity with which others retain it. Hence the earth has been considered as the grand reservoir of electricity; and, therefore, that a metallic communication between the rubber and the earth, was necessary as a road for the fluid to the machine. The friction at the rubber draws from the fluid a portion of its natural electricity, which forms an atmosphere round the glass cylinder, and is supplied by the communicating chain hung to the negative conductor *b*. This atmosphere is attracted by the metallic points of the prime conductor *c*, and conveyed by them from the cylinder to the surface of that conductor, which becomes positively electrified; i. e. possessed of more electric fluid on its surface than it possesses naturally. This super-quantity will endeavour to get back to the earth, or equalize itself with any conducting body near it;

and hence it darts into my knuckle, or into any metallic substance I hold in my hand, making the conducting moisture of my body a path-way back to the ground.

2d. I now take the chain from the conductor *b*, and hang it on the conductor *c*, which will then give no sparks; but when I address my knuckle towards *b*, sparks will again *seem* to strike me: but, in reality, they now dart from my hand to the negative conductor; I then convey the fluid from my feet to my hand, as before I conveyed it from my hand to my feet, as will be proved hereafter.

3d. I now take the chain away, and the whole machine is then insulated from the earth, as all its parts are sustained on non-conducting glass pillars. I also stick into the conductor *b* the wire *z*, bringing its knob within three or four inches of that in the conductor *c*. On turning the cylinder, strong sparks dart from the knob *q* to the knob *p*. How is this, when the whole apparatus is cut off from any communication with the earth, the grand reservoir of electricity? The conductors contain a natural quantity; but by the excitation, the conductor and rubber *b* becomes minus, or robbed of a portion of its natural quantity; while the conductor *c* receiving it, becomes plus, positive, or possessed of more than its natural quantity: hence the positive knob, *q*, delivers back to the negative knob, *p*, its super-quantity, in vivid sparks. This shews that bodies do not lose their natural electricity by being insulated from the earth. For where this natural quantity remains undisturbed, no electric signs appear; but when it is disturbed, as in the above experiments, then one part becomes positive, another negative; it is in a state of redundancy in one place, and in a state of deficiency in another; but each makes an effort to meet the other, to restore an equilibrium, and then all is at peace.

4th. If the wire *z p* be stuck in its conductor, so that its knob may be about an inch from the ground; and a similar wire and knob be stuck in the conductor *c*, so that its knob may also be about an inch from the ground;—so soon as the excitation begins, electricity will jump from the earth to the negative knob, and at the same instant from the positive knob into the earth; one drawing it from the earth, the other delivering it back to it.

SECTION III.

On Points.

THAT points, attached to conductors, both receive and deliver the electric fluid more easily than flat or round bodies, is evident from this experiment:—Hold the knob of a brass rod at such a distance from the prime conductor, that sparks may fly to it; then present the point of a needle to the conductor at twice the distance of the knob, and the sparks will cease; remove the needle, and the sparks will be seen again; present the needle, and the sparks disappear again: certainly shewing that the needle draws off the fluid in a stream silently; which may be seen like a star on the point of the needle, when the excitation is performed in the dark.

2d. Fix a wire, with a sharp point, into the end of the prime conductor, and hold a knob, or your hand, near it; no sparks will ensue; but a cold blast will issue from the point that will turn light mills, or wheels, as Fig. 10, which is a round piece of cork,

with the feather ends of quills stuck in it; a small needle is fixed in the centre of the cork, so that the whole can be suspended by the magnet *m*. On the cylinder being turned, an aura will issue from the pointed wire *w*, that will blow the wheel round with great swiftness.

3d. If another point be held half an inch from the point just mentioned, a beautiful stream of fire will be seen running from the electrified point into the other, producing a crackling kind of noise.

4th. Let the needle *n*, Fig. 11, be stuck perpendicularly into the prime conductor, with the four wire arms suspended on its point: if the ends of these arms be filed into points, and turned at right angles horizontally, and all in the same direction, when the machine is turned, the arms will whirl round, and exhibit a ring of fire in the dark. This is occasioned by the resistance the air gives to the electric aura, spouting out at the four points.

5th. If one piece of wire be bent as the two were in the last experiment, and suspended on a point, insulated by the glass support *a*, Fig. 12, and from one of the arms a small glass clapper be hung by a silken thread, *c*, and the glass support be stuck in the centre of eight surrounding bells; a chain being hung from the prime conductor, almost to touch this apparatus at *s*: when the machine is put in motion, the wire will circulate, and ring the eight bells. This pleasing effect depends on the same cause as the last. The chain being electrified, communicates electricity to the suspended wire; and as that is supported by glass, and the clapper by silk (both electrics, or non-conductors), the fluid has no-

where to escape, but from the points of the suspended wire; where its aura meets a sufficient reaction from the air to push it round.

6th. The electrical orrery is another device dependent on the aura that streams from electrified points. On a wire bent, pointed, and balanced as the last, let a small globe of glass be fixed, over its centre, as *a*, Fig. 13, to represent the sun: into one end of this wire let there be fixed a small well-pointed wire, half an inch long, and standing perpendicularly. On this wire the earth and moon's wire is suspended, as *w* in the figure: this wire is also bent like the letter *z*, having a round pith ball fixed on its centre to represent the earth; and a smaller, fixed on one of the angles, to represent the moon; the whole sustained by the glass *b*. When the chain *c* is fixed to the conductor, and the machine is excited, the sun will turn on its axis; the earth will have its diurnal and annual revolutions; and the moon will accompany the earth, making twelve revolutions round it, while the earth makes one round the sun.

7th. That this power is so considerable as to counteract the power of gravity in light bodies, is curiously exemplified in Fig. 14: a wire, having its ends pointed, and bent in contrary directions, like the last, is fixed to an axis of the same kind of wire, perpendicular to the direction of the points; this axis laid on the two parallel inclining wires *c* and *d*, will roll down them by its own gravity: but when it is nearly arrived at the bottom, if the machine be put in motion, the axis will return, rolling up the inclined plane. N.B. The supports *a* and *b* must be of solid glass.

More has been said on this part of electricity than may be thought necessary; but, connected as the subject is with those point-

ed rods used for the preservation of our dwellings from the effects of lightning, they have been considered as properly introductory.

From the ease with which electricity enters into, and issues from, points, together with its strong affinity to metals, it was a natural suggestion, that long metallic rods, terminating in one or more points, would draw lightning from the atmosphere silently, or in a progressive stream, and thereby prevent the mischief it often does when obliged to come in a body upon houses, trees, or substances that are bad conductors. For where conducting nails, iron cramps, bolts, locks, tongs, &c. are at a considerable distance, lightning seems to accumulate its force in proportion to the difficulties it has to encounter, or to the length of the non-conducting matters that separate one conducting body from another. These are the situations, where buildings, &c. suffer from lightning. Accordingly, to prevent this, long rods of iron, about three-fourths of an inch diameter, are screwed to the ends of one another, so as to reach about five feet above the top of the highest chimney in the house, and to go, as straight as the building will admit, down to the ground, into which its other end ought to penetrate five feet, so as to be always in conducting moisture. Leaden spouts, gutters, the sheet-lead covers on the hips of houses, are all good conductors; and if iron rods be fixed against the chimneys, and join the spouts and gutters, so that there be an uninterrupted continuation of lead or other metal into the ground, these are as secure conductors as the iron rods. N.B. One conductor seems only to secure a building to the distance of about ten yards around it; for at fifteen yards from a conductor a building has been struck.

In what manner points operate upon lightning, or electricity,

has been matter of much ingenious conjecture. When a spark is taken from a large conductor, it is larger and more intense than when taken from a smaller conductor, diminishing in size and brightness, but increasing in length, as the conductor diminishes; so that when the conductor ends in a point, the spark becomes invisible, but of such a length, that it is felt on the face like a cob-web at several feet distance. Suppose the electric atmosphere round the conductor *a*, Fig. 15, to be represented by the spotted lines, then may the aura be felt at *c* on the hand, and on the face (as above) at four or five inches distance; being thus repulsed into the air, or to conducting substances near it. The attraction which the conductor has upon the electric matter on its surface being, therefore, *as* that surface, and a point having no surface, the electricity can more easily enter into, or escape from, a point, than from a flatter body. When a shaggy feather is laid on the prime conductor, and the machine put in motion, the fibres of the feather will dart out radiantly, and presently it will take its flight from the conductor. The feather (though a very imperfect conductor) consists of so many fibres and points, that the electric matter can easily issue through them; and by electrical repulsion spread out the fibres: but when the feather becomes filled with electricity, a repulsion between it and the prime conductor takes place, and it is thrown off to any neighbouring body, that will take from it its superfluous electricity: it then becomes susceptible of being attracted to the prime conductor again, and becomes a carrier of electricity from it to the neighbouring bodies. But if while the feather stands erect on the prime conductor, the point of a needle be held at a foot distance from it, the feather will instantly cling to the conductor, as if afraid of the point. The point being of metal, is a better conductor than the fibres of the feather. Now if a feather, *a*, be stuck in the end of the prime conductor,

Fig. 16, and electrified, the fibres will become radiant, and have a repulsion in the direction of the arrows *c z q*: but if a point, *d*, be presented to it, a stream of electricity will issue from the feather to the point, and, by crouding to it, become condensed at *d*: that condensation will increase the repulsion of the point, and particularly in the contrary direction of the stream *; so that the repulsive power *d s*, being greater than the diffused repulsion *a*, *z*, will drive the feather back, and make it cling to the conductor as if afraid of the point.

Perhaps there may be something in the polish, and disposition of the pores, in a point, that is more friendly to the receipt and delivery of electricity, than in flatter bodies; for we find that it makes greater efforts, and seems to have more difficulty in making its way into large knobs than into smaller; so that a point being the least possible surface, electricity must needs enter it with the least difficulty, if made of conducting matter. Hence as the clouds may be considered as the outside coating of a Leyden jar, and the earth as the inside coating; and the non-conducting air between them as the glass of the jar: the Fig. 17 may assist the young electrician to conceive how a pointed conductor draws lightning from the clouds.

On the Attraction and Repellency of Electricity.

Electricity attracts all kinds of bodies, and is repulsive of itself. A feather hung by a silken thread within a foot of an electrified conductor, will be attracted to it, and instantly repelled. The

* When it is considered that there are a great number of bad conducting points from the feather, and but one receiving point of metal, the condensation at that point must be so great, that the *reaction* will overpower the emanation from the feathers.

electric atmosphere which adheres to the conductor, attracts the feather; a portion of that atmosphere immediately adheres to, and surrounds, the feather: now as the electric fluid is repulsive of itself, and the feather has acquired an atmosphere, as well as the conductor, the two atmospheres repel each other, as the arrows in Fig. 18.

2d. Thus, if four small bells be suspended by wires from two brass wire arms, *d* and *o*, Fig. 19, and on these arms be hung four clappers by silken threads, at a proper distance from the insulated central bell *a* (the support *c* being solid glass); if then a chain, *g*, form a communication between the wires and the prime conductor, and the machine be put in motion, the clappers will begin to move swiftly between the four electrified bells and the bell *a*, ringing the whole five. The four outside bells, communicating with the prime conductor, will be in a positive state, while the bell *a* will be in its natural state, because its support *e* is of metal, and communicates with the earth, by means of the table, the floor, and walls of the room. The clapper *z* being attracted to the bell *q*, receives an atmosphere of electricity, by which it becomes repelled from *q*, and attracted by *a*, where it delivers its atmosphere, and becomes liable to be attracted again: hence the clappers are the carriers of electricity from the electrified bells to the bell *a*, which keeps altogether in its natural state, as the stand *e* conveys away the fluid as fast as the clappers deliver it.

3d. Cut a few small figures in thin paper, as Fig. 20, and place them on the small metallic table *c*: let a thin plate of brass, as *d*, hang from the prime conductor just above the figures. When the machine is excited, the figures will get up and dance in a whimsical manner. The cause of which must appear, from what has

been said, to be the attraction of the electrified plate *d*, to which the figures jump, and are instantly repelled back to the table *c*; so that they become the piece-meal carriers of the electric matter from *d* to *c*.

4th. While the machine is in motion, put the knob of the prime conductor into the glass receiver *a*, Fig. 21, making the knob touch all the interior surface of the glass; then suddenly place it over a few small pith balls on the above table, when instantly the balls will begin to fly about the glass, and with a laughable commotion continue to do so for several minutes. When they cease, if a hand touch the glass, they begin to fly about again, and so on for several times. We shall see by the Leyden vial that the receiver was charged with positive electricity on its inside, and negative on its outside; and in that state was placed over the pith balls: the balls were attracted to the abundant side, and instantly repelled down to the table, as in the foregoing experiments, carrying off by degrees the positive quantity to supply the negative side. But when the equilibrium is nearly restored, the electricity becomes too weak to affect the balls, and they cease to jump: if then a hand or piece of metal touch the glass, they begin again; because a better conducting road is made between the in and out-side of the glass, so that the remaining electricity can make an exertion by means of the balls, the table, and the person who touches the glass, to make its way to the outside.

SECTION IV.

On the Leyden Vial.

THIS astonishing vial derives its name from the place where its effects were first discovered. It is a glass jar or bottle, coated both within and without, to the distance of two inches of its brim, with tin-foil, fixed on with paste or gum-water. It has a thin cover of baked wood, through the centre of which is stuck a strong wire, terminating in a number of smaller, that touch the inside coating of the jar; the top of the strong wire terminates in a brass knob, *a*, with a hole on its top to hold an electrometer*, Fig. 22. When the knob *a* communicates with the prime conductor, and the machine is excited, the ball *c* of the electrometer will separate from the ball *a*; and when its rod stands horizontally, it indicates that the jar is fully charged. If then one knob of the discharging rod touch the outside coating, and the other approach the knob *a*, when they come within an inch of each other, an explosion will take place between them.

The cause of this striking phænomenon has been variously accounted for; but as I have made it a rule through this work not to incumber it with divers opinions, or take up the reader's time with their investigation, I proceed to adopt that explanation which seems to me most agreeable to nature, analogy, and phænomena,

* An electrometer is an instrument for measuring the charge of a jar or battery; founded on the principle of electrical repulsion, as explained in the last section. It consists of a semicircle fixed as Fig. 22, and graduated into two quadrants. From the centre of the semicircle is suspended on brass pivots a small rod of wood, with a pith ball at its extremity.

founded on the observation and experience of above forty years. When a Leyden bottle is hung to the prime conductor, by a wire touching its inside coating, and its outside coating touches only the air, it will not receive a charge. The air, as well as glass, has so strong an affinity to electricity, that it parts with it with great difficulty; and being in general saturated with it, receives it with equal difficulty. Hence when electricity is excited, it adheres to the surface of the prime conductor for some time before the air (or perhaps the moisture in the air) can carry it off; and the interior surface of the bottle being in the same state, will have its electricity carried off also: when the discharging rod, therefore, makes the communication between its in and out-side coatings, little or no electricity appears. But when the outside coating touches any conducting substances that communicate with the earth, the rubber, or negative conductor; and the inside coating communicates with the prime conductor; the jar, or bottle, will charge and discharge as above. In the first place we must consider the electricity *inherent* in the glass as increased and disturbed by that thrown on its inner surface by the machine: accumulated on that surface, a proportional quantity is forced from the other surface into the conducting substances that touch the outward coating, as indicated by the arrows, Fig. 22; hence the inside is said to be plus, and the outside minus; or positive and negative: or, to be more explicit, the inside surface is in a state of superabundance, and the outside surface in a state of want. When, therefore, a metallic communication is made between the in and out-side coatings, the superabundant electricity (so induced upon the inner surface) makes an effort to restore the equilibrium of the two sides, by darting from *a*, the positive knob, to *e*, the knob that communicates with the negative side of the jar; this stream, joining the

propelled electricity, represented by the darts, Fig. 22, both return to the outside, and the equilibrium is restored with a flash and explosion at *a c*. The tin-foil coating only distributes the electricity equally over the surface of the glass; for glass may be charged without any coating, as in Fig. 23, where a blunt-ended wire, *a*, hangs from the conductor *d*, within half an inch of the plate of window-glass *g*: when the machine is excited, a brush of electrical light will fall from the wire *a* on the glass for a few seconds, and then cease; but if a blunt-ended wire, *n*, be held opposite the wire *a*, about half an inch from the under surface of the glass, the brush will re-appear, as well as a star on the blunt end of the wire *n*. After some time these effects will cease: but if the glass be moved so that the wires *a* and *n* may be opposite on various parts of its surface, the whole of the upper surface will be charged positively, and the under surface negatively, and a metallic communication between the two sides will produce a flash and explosion, the same as a coated jar.

2d. If a loose coating, or patch, of tin-foil be laid on the glass when sustained by a hand underneath, and the patch be electrified, and then shook off the glass, the other hand, applied to the place where it lay, will receive the electrical shock.

The *brush* indicates the delivery of electricity; the star its reception; so that it is ocular, that the upper surface of the glass, in the first experiment, had the electricity forced or induced upon it, while an equal quantity was propelled from the other surface into the wire *n*. If the glass, so charged, be removed from the machine, and a crooked wire, with its sharp pointed ends, be held in the position *o*, so that each point may be half an inch from the upper and under surface of the glass, the electricity will return from the under to

the upper side, making a brush below, and a star above; thus the equilibrium is restored.

Glass and air being non-conductors, it is difficult to force electricity out of glass into air, by any accumulation: hence the necessity of conducting substances being joined to the opposite side of the glass, or jar, to that on which the electricity is induced. Suppose *a c* one side of a plate of glass, and *d e* the other, Fig. 24, and that the natural electricity in the glass, and in the air on each side of it, was represented by darts, both being in a quiet state.—But now we will suppose this quiet state to be disturbed by the near approach of the electrified conductor D, Fig. 25, from which electricity will be repelled in the direction of the darts *r s*. This will disturb and repel the electricity within the glass plate *n o z q* to the pointed metallic receiver E. If now the glass plate be removed, the side *n o* will be found in a positive state, and the side *z q* in a negative state; and a metallic communication between the two sides will produce the electric flash and report. This I hope may be conceived as a picture of what passes in the glass of the Leyden bottle, when exposed to accumulated or condensed electricity; and also the theory of charging plates of air, of wax, of crystal, of resins, and all other electric bodies.

That plates of air can be charged like plates, or jars, of glass, is evident from the experiment, Fig. 26: *a* is a circular smooth board, of two feet diameter, suspended from the prime conductor by the chain *g*; it is covered with tin-foil, and hangs a few inches above a similar board covered also with tin-foil, which communicates by conducting substances with the earth. If the machine be put in motion, the chain *g* and plate *a* will be positively electrified, and repel the electricity of the plate of air between the boards *a* and *e*

into the board *e*, and the substances in contact with it; *a*, therefore, represents the inward coating of the jar, Fig. 22, and the board *e* the outward coating: if one knob of the discharging rod touch the board *e*, and the other the board *a*, the flash and report will take place as with the Leyden jar; or if one hand touch the board *e*, and the other the board *a*, the electric shock will be felt; proving that the plate of air between *a* and *e* can be charged the same as glass.

N.B. The edges of the boards should be made round and smooth, for edges and points disperse electricity: and if the upper board were suspended from the ceiling of the room by silken cords, so much the better.

2d. Two rulers, like two black-lead pencils, are covered with tin-foil, and sustained on the glass pillars *a* and *b*, Fig. 27. From the end of each ruler hang two pith balls by fine flaxen threads. When these rulers touch each other as in the figure, and a clean warm glass tube, *z*, be rubbed with a dry silk handkerchief, and held in the position as in the figure, and so as to have a plate of air between it and the end of the ruler *a*, the natural electricity contained in the two rulers will be repelled towards their extremity, as denoted by the darts. If, while their electricity is in this disturbed state, the pillar *b* be removed from *a*, its ruler and balls will be found in a positive state, while those of *a* will be found negative, or in a state of want: this may be proved by bringing the excited tube *z* within a few inches of the balls sustained by the pillar *b*, which balls will be repelled; but if the tube be brought near the balls sustained by *a*, they will be attracted. It has before been observed, that electricity repels itself; and attracts, or is attracted, by all other bodies. Hence the balls sup-

ported by *b*, being in a positive state, repel each other, and those supported by *a*, seem also repelled; this arises from being deprived of their natural quantity, and soliciting a supply from the surrounding bodies, towards which they have a natural attraction.

3d. Fig. 28 is a small coated jar, standing in a cup of tin, and supported by the solid glass foot *s*. From the knob communicating with the inside coating of the jar, there projects a wire, sustaining, by fine flaxen threads, the pith balls *z*; and from the tin cup, a wire also sustains a pair of pith balls. I take the jar out of the cup, and touch an electrified conductor with its knob, and the balls *z* instantly separate: I then replace the jar in its cup, and the balls remain separate; but if I touch the knob *a*, the balls *z* close, and the balls *x* open: if I take my finger from *a*, and touch the outside coat of the jar, the balls *x* close, and the balls *z* open; so that if the in and out-side of the jar be alternately touched, the balls will separate, and close alternately for hundreds of times. Here, then, is a proof, that there is an influence operating in, and through, the texture of the glass, though we consider glass as a non-conductor. To explain this, it will be necessary to observe, that by touching the electrified conductor with the knob *a*, the jar became positive on its in, and negative on its out-side, agreeable to what has been said on the Leyden jar: in this state it was insulated in the tin cup, by the glass leg *s*. I now touch the knob *a*, and carry off (by the conducting power of my body) a portion of its positive electricity, and the balls *z* close by that loss. What, then, has passed in the texture of the glass? The electricity, forced towards its outside by the charge, now returns towards the inside, and leaves the outside more negative than it was; hence the balls *x* diverge in search of electricity to supply their want: I then touch the outside, and by supplying that

want, the balls *x* close: but now the electric matter vibrating towards the inner side of the glass (with a kind of flux and reflux), a weak positive again separates the balls *z*. By touching the knob *a*, the balls *x* again become negative, and expand in search of electricity: and as the surrounding air (if dry) is not disposed to part with it, the effort will continue for a considerable time, &c. &c.

I conceive these to be decisive experiments in favour of glass, and other electrics, possessing a superabundance of electricity, naturally; of their retaining it with a strong chemical affinity; of its liability to be disturbed, compressed, or forced, by stronger condensations from powerful electrical machines, or lightning; and that forcing this power is something like the forcing wool, or other elastic substances, into a package already full; or compressing water into a metallic vessel, so full, that the superabundance must be squeezed through the metal.

END OF THE FIRST LECTURE ON ELECTRICITY.

LECTURE VIII.

SECTION I.

Of Spontaneous Electricity.

THOUGH this mode of exhibiting electricity appears to be without friction, it is only so where it passes between bodies containing unequal portions of it. The tourmalin is a red-coloured semitransparent fossil found in Ceylon, that has the property of shewing signs of electricity, by being warmed, or heated, differently from other electrics. When heating, one side is positive, and the other negative; when cooling, that which was positive, becomes negative, and the other side positive. Is not this because it is an electric that holds its electricity so loosely, that the friction occasioned among its parts by heat, is sufficient to excite, and give it motion? If a piece of window-glass be laid on a warm poker, and the tourmalin on the glass, the glass will become negative, and the side of the stone touching it, will be positive. Is not this another instance of the relationship between common fire, and electricity? The heat excites the tourmalin, and qualifies it to absorb electricity from the glass; the glass of course becomes negative, while the fossil is positive.

Electricity does not appear over the whole surface of the stone, but only on two opposite sides, like the poles of a loadstone; so that its virtue lies in the direction of its strata, and, therefore, is capable of being forced, or drawn, to or from one pole towards the other, by heating, cooling, or friction. When put in the fire, it covers itself with ashes; when rubbed with silk it emits strong flashes; and is luminous when warmed in the dark; so that changing the degree of heat, is what excites the stone.

2d. Sulphur melted in a glass vessel exhibits spontaneous electricity; the glass is positive, the sulphur negative. If poured into a metal cup, and left to cool, it shews no signs of electricity, but separated from the cup, the sulphur is plus, the cup minus. So melted chocolate, as it cools in the tin pans, is strongly electrical. These, and many other substances, are so expanded by heat, that when they cool and contract, a friction takes place sufficient to excite electricity.

3d. Vapour carries off latent electricity. Place a metal cup, *a*, on the electrometer * *c*, Fig. 29, with a little water in it; if then a red-hot coal be dropped into it, a vapour will arise that will carry off a portion of electricity from the cup, the cap, and the leaf-gold. The leaves will instantly part, and fly to the slips *s s*, to supply their loss; of course they part with negative electricity: but the wire *p*, held by the sealing-wax, or glass, *q*, in the vapour, will have its pith balls *d*, part with positive electricity. Here it is evident that vapour carries off electricity from water, or whatever

* Bennet's electrometer, is a cylinder of glass, *c*, fastened into the metal bottom *m*. From the metal cap *z* is suspended two slips of leaf-gold, *n n*, about four inches long, and half an inch wide, reaching near the bottom. Two slips of tin-foil, *s s*, are pasted to the glass cylinder parallel to the leaf-gold.

else it is in contact with; and, perhaps, the vapour derives its volatility from its union with electricity; for it is observable, that if insulated pith balls be suspended in a fog, or mist, they separate with positive electricity.

4th. If an hollow cone of tin, as Fig. 30, filled with a quantity of coiled-up wire, be held by the glass handle *a*, over the insulated vapour, or flame of molten resin and bees-wax, the electrometer balls, *c*, will part with negative electricity: these being substances when excited that attract electricity from bodies they touch, and therefore are said to produce negative electricity.

Smoke resists the passage of electricity: flame greedily absorbs it. Fix a Leyden bottle to the end of a metal rod, which will serve as a handle; let the bottle be charged, and passed rapidly through the flame of burning paper, straw, or any other combustible, and it will be as effectually discharged, as if the discharging rod made a communication between its out and in-side coating: pass it in the same manner through smoke, and it will remain charged: but if held charged in an hot oven, it will lose its charge as before. Do not these effects imply the relationship between electricity and flame, or fire? Is not flame a conductor from that affinity, and from displacing the non-conducting air?

6th. The conducting power of flame is beautifully exemplified, by bringing the knob of a charged bottle near the flame of a candle, as Fig. 31. If the knob *a* communicate with the outside coating of a charged jar, and the knob *c* with the inside coating, and each be held two inches from the candle, and opposite each other, the flame will spread towards each, and a discharge will be made through it:

Shewing, that the weak negative will make an equal effort to meet the stronger positive, as if their power were equal.

SECTION II.

Of Lightning.

THIS might be considered under the head of spontaneous electricity; for, that lightning is electricity, there can be no doubt, from their effects being the same. If a kite be held in the wind by a small soft iron, or copper, wire, instead of a string; and the wire be coiled round a strong rod of solid glass, held in the two hands; sparks may be taken from this wire, and jars charged as by a common electrical machine. In making this experiment, it is necessary to let a key hang by a wire from that which is coiled up, so as to touch half a crown, or any plate of metal lying on the ground; by lifting the key a little from the plate, a stream of fire will be seen between the key and the plate. But if a sensation, like a cobweb, on the face, takes place, it will be prudent to throw down the glass rod, and leave the kite to itself. The effect of sparks takes place, whenever a kite can be raised, at all times of the year. 2d. If a long wire, screwed into the knob of the Leyden bottle, and pointed at its extremity, be held aloft in the open air at night, when thunder and lightning is near, a star will appear on the point; and if the other hand touch the wire, a shock will be received. 3d. I stand on a glass-footed stool, Fig. 32, with a fishing-rod (covered with tin-foil, and with several points at its extremity) in my hand: if the feet of the stool are very dry and clean, when the rod is held out at the window, or up in the

air, it seldom fails to attract an electric atmosphere, and put me (in general) in a positive state, which is indicated by touching the electrometer, and trying whether the leaf-gold opens with positive or negative electricity. A small lighted torch fixed to the fishing-rod, as at *c*, assists the extraction of electricity from the air: perhaps by rarefying the air around it, and thereby relaxing the strong union between the air and electricity. 4th. Animals killed by lightning, putrify in a very short time; so do those killed by electricity: perhaps, in both cases, by their blood vessels being ruptured.

The identity of lightning and electricity being thus established, let us try to form a conjecture, from whence it comes and whither it goes. Hitherto we have considered light as the primary emanation from the sun; but as I hope it has been proved that fire, light, and electricity, are but modifications of one and the same principle, it is no great deviation from the first hypothesis, to conceive electricity rather as the matter of the sun's atmosphere, and which, by its natural repulsion and the sun's centrifugal motion, becomes projected from him into infinite space; where it meets and mixes with similar emanations from other suns; so that all space is probably filled with this subtil and powerful matter. Though the momentum of light might seem (from what has been said on that subject) too inconsiderable to give annual and diurnal motion to the planets, here we have an emanating principle, whose power is irresistible, and equal to the task of giving motion to a world! and perhaps the vivifying spirit to its plants and animals! The part of this subtil matter that impinges on our earth, meets first the uppermost region of the atmosphere, which is a conductor, and admits the fluids (for thin or rarefied air conducts electricity); but as it approaches the lower and more dense part of the atmosphere,

it meets increasing resistance, and is often obliged to force its way through the non-conducting lower regions; producing the terrible corruscations and explosions of thunder and lightning. In the clouds it meets with a receptacle (for water admits and conducts electricity), and when those clouds are not overcharged, the air is in peace. Now if we consider the clouds as one of the coatings of the Leyden vial, the lower dense air, as the glass, or electric, and the earth as the other coating, we may contemplate the Leyden bottle upon a grand scale, producing thunder, lightning, earthquakes, and the aurora borealis. Fig. 33, *a*, is a portion of the earth's surface; *c* the lower non-conducting part of the atmosphere; *d* the clouds; *g* the positive electricity of the clouds, met by the negative, *q*, of the earth; *n* the explosion; *z z* the electric stream from the sun. When the air is very dry, and much saturated with electricity, it resists the entrance of more; and hence the reason why thunder generally follows such weather, and is more prevalent in summer than winter. When the air is moist, electricity finds an easy passage into the earth, without commotion; and hence the earth has been generally considered as the grand reservoir of it; and from that reservoir we pump it by electric machines and other frictions, being incapable by such means of exciting much from the air. When the rays of electricity, therefore, come the most directly on the earth, as in summer, a greater quantity may be poured on the dry air than it can conduct, and hence the clouds will be in a positive or abundant state, while the earth, comparatively, may be in a negative state; the consequence will be a violent effort to restore equality by a storm of thunder and lightning; and the air near the earth will be found positive and negative by fits, while the storm lasts. When the clouds are scattered at a distance from one another, the lightning is often seen darting from one to another, where the air is too rare or thin to form much resistance to its

passage, and then we see lightning without hearing thunder. When the electric stream from the sun falls obliquely on the earth's atmosphere, as in winter, it is seen streaming through the upper regions of the air toward the north, and is called the aurora borealis, streamers, or northern lights. The same phænomenon is also seen towards the south pole of the earth, when the solar stream darts obliquely upon it, or makes a chord with the atmosphere. This phænomenon is never seen in or near the torrid zone, because the sun's rays fall direct upon those parts, inducing electricity on the upper, and forcing it through the lower regions of the air into the earth, where it lies quiescent till called forth by frictions or affinities. One of those affinities is water, to which it adheres with great affection, separating its particles, and giving them volatility. And though they rise together through a medium, conceived to be already full of electricity, yet as the particles of electricity repel each other, and that repellency is increased by the heat the opaque earth receives from the sun, the evaporation goes on, water rises through the air, flying on the wings of electricity, till it arrives in those cold and rare regions that are conductors of electricity (for air approaching to a vacuum is a conductor). To this rare, or thin air, electricity has a greater affinity than to water; the water becomes forsaken, and its particles attracting each other, form little assemblages, at a small distance from each other, and appear as clouds. These assemblages increasing, soon become specifically heavier than the air in which they float, and begin to descend; picking up more, they become drops, and fall to the earth. That evaporation is thus carried on, may be proved by hanging a pair of small pith balls, by flaxen threads, in a receiver, and electrifying them positively: if the receiver be placed on the air-pump, and exhausted, the balls will close; but when the vapour becomes decomposed, and descends in the receiver, the balls open with nega-

tive electricity; shewing that the rarefied air absorbed the electricity, and left the water to which it was united: thus forsaken, both by the air and its electricity, it falls, within the receiver, a real shower of rain. A precipitation of snow is but the above little assemblages of water frozen and sticking together in flakes. This phænomenon is often produced artificially in crouded assembly-rooms at Petersburg, by letting in the cold air from the top of the room, which will suddenly condense the floating vapours, and make them fall in small flakes of snow. Hail is a frozen drop; or, often, several drops united into one great hail-stone.

That lightning may sometimes break through the atmosphere to the earth, when thick clouds, one above another, make a conducting road for it, is very consistent with its nature. Such clouds generally appear when a waterspout takes place; which begins like a spiral pipe from the lowest cloud, and descending towards the sea, is met by a whirling protuberance of water from the surface: this I take to be the electricity of the water, making an effort to meet that of the clouds; for the negative electricity of a charged jar will endeavour to meet the positive with as much energy, as the positive will the negative. If we, therefore, conceive a strong electricity from the cloud met by a weaker from the sea; and that the track made both by the ascending and descending electricity will be a vacuum in the air, to which the winds will rush in all directions, and form a whirlwind; water, either ascending or descending, in such a vortex, will necessarily be formed into a pillar-like figure. When these effects take place over the land, we find the earth torn up, as if blown up by gunpowder. Sometimes the effect is progressive; then have we waterspouts travelling from the sea, and breaking in a deluge upon the land. When this progress happens in a wood, we find vistas made through it, by trees torn

up by the roots, broken, and thrown in all directions! Such is the power of this wonderful agent.

It is observed, that earthquakes only affect the outward surface of the earth; that mines, and even wells and springs, are little injured by them; and that the tremulous motion is quite external. It follows that they are not occasioned by internal explosion. (This is to be understood of earthquakes that happen at a distance from volcanic matter; for internal causes may *then* operate.) What power in nature, then, is capable of producing a vibratory motion over many square leagues of the earth's surface? I think accumulated electricity. The air preceding the earthquake is always hazy, but not like the haziness occasioned by moisture; it seems surcharged with fiery, rather than aqueous vapours. The atmosphere is of a red colour; the air is still; birds, beasts, and all nature seem aware that something terrible is approaching. The first shock is as if the earth vibrated to and fro; or, as if waves like the sea heaved up the earth progressively. This cannot be the effect of internal explosion, because no internal mischief or derangement takes place. May it not be an overcharged atmosphere, labouring to discharge its electricity into a dry earth, ill disposed for its reception? for dry earth is a tardy conductor of electricity. But earthquakes generally happen on the banks of rivers, or banks of the sea; and accordingly the water does not receive a vibratory shock of the same kind that the land does, though the commotion is here also violent and irregular, but receiving the electric matter from the atmosphere at once (as being a good conductor): the effect on ships, or bodies in the water, is as if something hard struck the ship, or the body in the water. For if the hand be immersed in a glass bowl full of water, when a strong shock from an electrical battery is sent through the water, the

hand will receive a blow very unlike an electric shock, but very like what I conceive the ships in the Tagus felt in the great earthquake of Lisbon.

An humble imitation of those effects may be produced by the two circular boards, Fig. 26, about two feet in diameter, their edges rounded, and the whole covered with tin-foil. Let one be suspended from the ceiling by clean silken cords; and the other sustained on glass feet, parallel to the other; but so as to be brought nearer or farther from one another. If the upper board be connected with the conductor, and the lower with the earth, and separated about two inches distant, and electrified; one hand touching the lower, and the other the upper, a shock will be received as from the Leyden bottle; for, as has been shewn, it is but a plate of air that is charged instead of a plate of glass; the upper board being in a positive, and the under in a negative, state: the shock being in proportion to the quantity of electricity, and the ease with which it can escape from the positive side of the electric. The two plates strongly attract each other, and would come together, if not kept asunder by force: sparks flying between them will frequently destroy the electricity of each. If the under surface of the upper plate be covered with gilt leather, and a smooth shilling be laid on the lower plate; beautiful ramifications will fly about the leather, and dart to the shilling, when electrified. In this experiment the upper plate naturally represents a positive cloud, and the under one the earth, with the manner in which lightning darts from the clouds to the earth; and if a Leyden vial be connected with the conductor, the flash and report will be still greater.

2. A whirlwind, or waterspout, may be naturally exhibited by

laying a spoonfull of bran on the under plate, and taking off its chain. When the upper plate is electrified, and the hand now and then touches the lower, the bran will assemble in one place, and form a kind of column between the two plates, and whirl round, then shift to different parts of the plate, and after some time fly off and disperse about the room.

These appearances are so exactly similar to thunder, lightning, tornados, waterspouts, &c. that, on the hypothesis of electricity emanating from the sun; being received and conducted by the thin air of the upper part of our atmosphere, to the clouds; and stopt there, by the non-conducting dense air below, from uniting with the earth, to which it has the strongest affinity; may we not believe that its efforts to pervade, or get through, the resisting air of the lower atmosphere, produces the above effects?

SECTION III.

Of Animal Electricity.

THAT the animal nerve is a vehicle for electricity, and perhaps the cause of sensation, many experiments make more than probable. In the torpedo, we find an electrical battery, abstracted from the vessels appropriated to the animal functions; it consists of a great number of vessels like an honey-comb, standing across the fish, from its belly, to its back; so that if one hand touches the belly, and the other the back, an electric shock is instantly felt, and the

fish is convulsed. If the fish be touched with a stick, a numbness seizes the hand that holds the stick. The same effect takes place, if a charged battery be touched with a stick, because the stick is a bad conductor, and the electric matter can only pass through it in a stream, benumbing the hand in its passage; but a regular conducting power from its positive and negative sides, would be a shock. The electric eel, or gymnotus, has a stronger electrical power than the torpedo: the head and shoulders of this fish contain the animal functions; the rest seems all electrical; and electrical by volition, for the creature has the power of exerting or witholding the shock. If one hand be put in the water, and the other touch the eel, a violent shock takes place. I have electrified thirty people at once with this eel; and sparks have been produced by that electrical circuit. How these two species of fish collect and retain their electricity, in a conducting medium, is an inexplicable wonder; they were no doubt endowed with this power for defence, and catching their prey; and have organs to secrete it from the water, as other animals secrete nutrition from the heterogeneous contents of the stomach. The nerves seem not designed to admit, or transmit, any animal fluid; they are kept moist by an indolent lymph; and are transparent across and lengthwise, as if intended to give a direct passage to *light*. If electricity and light be the same, (but differing in circumstances,) may not this transparency be strongly indicative of their capacity to transmit electricity? But this conducting power is proved by the late experiments made on frogs, and other cold animals. This barbarous experiment requires the frog to be divided in the middle by a pair of scissars, and the skin taken off. The viscera of the hinder part is cut away, so that the vertebræ may be laid bare: the two nerves will then be plainly seen, that give articulation to the hind legs, which being raised with a needle, a portion of the vertebræ may be cut away, so that the other part of it may be

united to the hind legs by the above two nerves, see Fig. 34; if round the remaining vertebræ a little tin-foil be wrapped, as *a*, and the legs be laid on a piece of zinc or on half-a-crown, as *c*; if by a crooked silver wire, *d*, the tin-foil and zinc be touched at once, the legs of the frog start up, and are strongly convulsed. 2d, If the two legs be put in a wine glass, full of water, and the piece of vertebræ wrapt in tin-foil in another adjoning one, see Fig. 35; and if then the bent silver wire *d* touch the water in each glass, the legs of the frog instantly jump out of the water! Are not these strong indications that the influence of the brain and nerves upon the muscles is of an electric nature? 4th, The nerve of the limb of an animal (recently killed) being laid bare, and its end armed with tin-foil as above; if a communication be made between the tin-foil and any neighbouring muscle by the silver wire, or one of zinc, strong covulsions will be produced in the limb. 5th, Or if the metallic communication be made between the armed and bare part of the nerve, the contractions will also take place. 6th, A similar effect is produced, by touching the armed part with different metal. 7th, the amputated limb of an animal, being placed on a table, and its principal nerve laid bare, and held by one hand, while the other touches half-a-crown, with a piece of zinc (the half-crown lying in the water that communicaties with the limb), the limb instantly becomes convulsed. 8th, Animals almost dead become considerably revived by exciting this influence. And if a live flounder be laid on its back, on a plate of copper, and an half-crown be placed on its belly; on making a metallic communication between the two metals, the flounder leaps up. 9th, In animals killed by opium, or corrosive sublimate, or starved to death, or killed by an electric shock, little or no contractions are produced. Zinc appears to be the best exciter when applied to gold, silver, molybdena, steel, or copper; but it must be observed that two different kinds of metal must be used in making the circuit, such as

zinc and gold, silver and tin, tin and lead, &c. 10th, If a medal of zinc be introduced under the tongue, and a crown-piece be laid on the tongue, and the edges of the two pieces be made to touch, the nerves of the palate are affected by a strong phosphoric taste. 11th, If the piece of zinc be introduced between the teeth and upper lip, near the eye-tooth; and the crown-piece be pushed far under the tongue; and then the edges of the two pieces be made to touch, a flash of lightning is seen by the eyes, even though the person be in the dark, or hoodwinked. 12th, If a person stand on the electric stool with glass feet, and touch the prime conductor for a few minutes, while the machine is working, his pulse will be greatly accelerated; and if bled in that situation, the blood will be projected from the vein to a considerable distance: shewing that electricity stimulates the motion of the heart, and increases this motion of fluids, &c. &c. Can any doubt remain that the wonderful agent is a prime instrument in muscular motion?

That different kinds of metals are necessary in producing these effects, may arise from the different quantities of specific electricity contained in them; gold contains more than silver; zinc more than tin, &c. so that when these different metals are put together, or come in contact, an insensible equilibrium takes place among them: or when they are separate, as *a* of zinc, and *b* of tin, Fig. 36, if a communication be made between them with a wire of gold or silver, as *d* (for it is found that the purer the metal, the better is its conducting power), an equality takes place. If a medal of zinc, therefore, be worn in the pocket with silver, and instantly used from that situation, they will not produce on the eye the sensation of a flash of lightning, as above. If one of these metals be, therefore, considered as plus, and the other minus, may not the equilibrium made between them by the wire *d*, Fig. 34, put the elec-

tricity of the nerves, *z*, into motion, and by that means stimulate the expiring muscles to action?

Electrophorus.

This apparatus exhibits a continual electricity. It generally consists of a cake, made of a promiscuous mixture of melted wax, resin, sulphur, pitch, &c. made even and smooth at the top. A plate of metal, or wood, covered with tin-foil, has a solid glass rod fixed perpendicularly in its centre, by which it can be lifted. If the wax cake be warmed, and rubbed with dry cats'-skin, or flannel, electricity will be extracted by it from the rubber and the hand, and an atmosphere may be felt on the surface of the cake. After excitation, if the metallic plate be placed upon the cake by its glass handle, and touched by a finger, when lifted from the cake, the metallic plate will draw a spark from the finger. This may be repeated for an hour together, and still the plate will draw a spark from the finger. Why? Electricity is repellent of itself: the quantity induced on the cake by friction, repels a quantity from the metallic plate through the touching finger; but in the act of this repellency the plate is lifted from the cake by the glass handle, and of course left in a negative state (as the electric stream is by this means broken): a finger, therefore, approaching the plate, gives it an opportunity of restoring its loss by a draught from the finger. As the cake has only exerted the *influence* of its electricity, and little of the electricity itself is lost or expended, this operation and effect may be repeated for a great number of times; and with a machine, containing inflammable air, candles may be lighted in the night by the electrophorus, as it will retain its electricity for many hours in a dry room. A repetition of

placing the plate on the cake may also be considered as a continued friction and excitation; for the bare removal of cakes of chocolate from their pans, or sulphur from the moulds into which it has been poured, will excite electricity.

Medical Electricity.

"Fire is the first mover in the animal machine, and the chief active principle during its existence; and as electricity exhibits so many phænomena which cannot be distinguished from those of fire, we are naturally led to conceive high ideas of the importance of this fluid to medicine." The agency of electricity in animated nature, has been proved by the experiment made on the torpedo and electrical eel. The number and magnitude of the nerves, in these animals, bear no proportion to their size; nor do they seem necessary for their motion, subsistence, or generation; it, therefore, seems to follow, that they are intended for the formation, collection, and management of the electric fluid; particularly as the will of these animals commands these powers. Variety of facts clearly proves the electric fluid to be essentially connected with the human frame; it will dart from long hair when combed in frosty weather; it will inflate a silk stocking when drawn from the leg. In damp and hazy weather, when electricity is carried off from bodies by humidity, our spirits become languid and our sensibility less acute; the nerves lose their tension and elasticity: and on high mountains spontaneous flashes have darted from the fingers, the body containing more than the surrounding rarefied, and conducting air; an electric shock has given tone to a flaccid fibre; has rendered palsied limbs plump: the electric aura from a wooden point has dispersed an infant cataract in the eye; and when issuing

from a metallic point, has restored the languid circulation of a local part to the condition of the rest of the body. Insulated, and connected with the conductor, the pulsation is increased: by this mode both male and female obstructions have been removed. Sparks administered to chilblains, have, in assisting the circulation of the blood, generally effected a cure. Even the last effort of expiring life is called into action by electricity, when every other stimulant has failed. Can we doubt then that this vital fluid is the cause of *muscular motion?*

If a battery be discharged through a mouse from the head to the tail, it will kill the animal: but after death, if an equal charge be sent the same way it will pass visibly over the body of the mouse, and not through it; proving that the power or medium which transmitted the shock was lost with its life.

For the application of electricity, it is necessary to have a Leyden jar, like Fig. 60, where the knob *b* is insulated from *a*, by the glass support *c*; and the brass rod *b d* will slide easily through the metallic socket *e*, so as to make the shocks greater or less. A pretty large forceps, A, should accompany this jar, turning on the joint *g*; and having its legs *n n* of solid glass rods. This forceps applies to any part of the body; thus: Suppose shocks are wanted to quicken a languor of circulation in the upper part of the arm; place the knob *r* on the shoulder, and the knob *s* near the elbow, and slide the knob *b* within a quarter of an inch of the knob *a*, having the wires or chains, *y* and *z*, as in the figure; if now the chain *u* be connected with the conductor, and the machine be excited, the fire will jump from *a* to *b*, and the part will receive a shock in proportion to the distance of *a* and *b*.

But a better effect is produced by letting the charge pass in a stream through the part. Draw *b* from *a* as far as the socket *c* will admit; and disengage the wire *z* from the knob *s*; this knob when unscrewed from the forceps, should discover a point at *s*. If now the knob *r* be placed on the shoulder, and the point *s* be brought near *a*, the fluid, condensed in the jar, will flow through the arm in a dense slow stream, and produce a considerable degree of warmth.

EXPERIMENTS,

MISCELLANEOUS AND ENTERTAINING;

ILLUSTRATIVE OF THE AFORESAID DOCTRINE.

BEFORE we proceed to the experiments, it will be necessary to reconsider the electrical machine.

1st. *To shew the course of the electric fluid.*

Fix into the remote end of the positive conductor *c*, a wire about six inches long, with a small ball at its extremity: excite the machine, and hold the flame of a wax taper near the ball, and the flame will be pushed horizontally from the ball, in the direction of the electric fluid. Remove the wire and ball into the end of the negative conductor, and the flame will be pushed towards the ball: shewing that the exciting rubber draws the electric fluid from the earth, and air; and that it issues from the positive conductor.

2d. *To make electric attraction and repulsion ocular.*

Fix a pointed wire perpendicularly in the positive conductor, and let another pointed wire, from the negative conductor, approach it within an inch, and directly over it. When the machine is worked, both points will be luminous; the positive, or delivering point, with a brush; and the negative, or receiving point, with a star. If now an excited tube of glass be brought near the positive point, its brush will be repelled sidewise (for they are both positive), and if the excited tube be held just opposite to the point, the brush will instantly vanish: but the excited tube being held near the negative, or receiving point, its star will turn towards the tube, and be visibly attracted. As excited sealing-wax absorbs electricity from its rubber, or other bodies with which it comes in contact, if it be held near the brush, it attracts it, if near the star, it repels it, contrary to the effects of the excited glass.

3d. *The electrical spider.*

Cut a small piece of pith, or cork, into the shape of a spider; run a threaded needle lengthwise through it several times, cutting the threads, so they may hang from each end of the cork, see Fig. 37; let the spider be hung from the ceiling by a dry silken thread, and the charged vial placed with its knob near it; the spider will then be attracted to it, and becoming possessed of positive electricity as well as the vial, will be repelled to the knob *d*, where it will deliver its electricity, and of course be attracted to the knob *b* again. Thus will it continue to carry the positive quantity piecemeal from the in, to the out-side, till an equilibrium is restored between the two sides.

4th. If a wire with an hollow light ball at each end, be suspended on a point supported by the glass rod *n*, Fig. 37, and a metallic rod, *s*, stand near it, on the same side with the charged jar; the knob *c* will be attracted to the knob *b*, and receive a small portion of its electricity, and therefore be repelled; but that repellency will drive the knob *g* to the rod *n*, where it will deliver its electricity, which will find its way to the negative side of the jar, along the wire *z*. Thus will the suspended wire vibrate between the jar and the rod *s* for several minutes, till the jar is exhausted.

5th. *Positive and negative sides of Leyden jars, proved by the double jar.*

Let *m*, Fig. 38, be a small jar, standing on a round plate fixed into the knob of the large jar *n*. Let the outside coating of the small jar, *m*, touch the prime conductor so long, as to charge the large jar *n*; then draw both from the machine. The lower jar is now charged; but the upper one is not charged; because, though its outside coating communicates with the positive side of the under jar, it cannot be charged itself, since the knob of its inside surface communicates only with the non-conducting air: (for a jar cannot be charged positively, on either in or out-side, except its opposite side communicates with the earth directly, or indirectly). If now the crooked wire *s* touch the negative side of the lower jar *n*, and its other end touch the knob *x*, a portion of the natural quantity of the small jar will be forced out, by the positive quantity on its outside, with a flash, and report. The upper jar now becomes charged; for its inside is negative, from what it has parted with; and its outside positive, from communicating with the positive side of the lower jar. If then the bent wire *u* touch the knob *x*, and its other end the outside coating of *m*, a flash will take place at *z*. Now what was taken out of *m*,

is restored from the lower jar, and *m* may be said to be again in its natural state. But if the wire *s* again touch the jar *n*, and its other end the knob *x*, the quantity taken out of *n*, and put into *m*, will exhibit a flash at *x*, in its way to the negative side of *m*. A little more may be taken out of *n*, by touching the knob *x*, and then the outside of *m*, as before; and this again restored to the outside of *n* by the wire *s*. By repeating these, more than twenty flashes may be produced while the electric matter is thus slowly exhausting from the lower jar *n*.

6th. *By a small pyramid, to prove the danger of breaks, or interruptions in thunder rods.*

Let a wooden pyramid, Fig. 39, be made in several pieces, with a wire through each, so that their ends may touch, as *s s s*. Let one corner of the pedestal *d* be loose, and have the safety-wire pass almost through it, but not quite. The wire passing through the rest of the pedestal, must join (by a chain) the outside coating of a Leyden vial. If the cloud *x* be supported by a wire from the prime conductor, and hang half an inch from the knob *g*, of the pyramid; when the vial is charged, a flash will take place between *x* and *g*; the lighting will pass along the wires *s s s*, till it comes to the break at *d*; there an explosion will take place, that will drive out the corner stone *d*, and let down the fabrick.

7th. *An electrical explosion displaces the air.*

Shape an half-inch board like the gable end of a house, as Fig. 40; fix it perpendicularly on the board *d*; cut the square hole *a* through it, and close up the back part of it with a square piece of window-glass. Cut a piece of board, that will loosely

fit the square hole, and fix a wire diagonally into one side of it, as *c n*. A wire, *x n*, terminated by the knob *x*, also is fixed superficially into the gable, as well as the wire *c z*. If now the knob *x* be placed within an inch of the prime conductor *k*, joining the vial *v*; and the outside coating join the wires by the chain *q*; as the jar is charging, a flash will take place between the prime conductor *k* and the knob *x*, but no mischief will be done; for there is a regular road for the fluid along *x n c z q v* to the negative side of the vial. But let the square piece of wood be taken out, and its wire placed against the glass on the back of the hole, and in the direction *a s*, instead of the direction *c n*; when the stroke takes place from the prime conductor, the square piece of wood will be thrown out to a considerable distance by the explosion behind, as may be seen through the glass: and, that the swelling of the air was the cause, may be felt by fixing the square piece *o* in the hole; this piece has a small tube fixed in it, so that when the explosion takes place, the hand held before the tube will feel a blast of air strike it.

8th. *A further illustration of the theory of the Leyden bottle.*

Insulate the bottle, as Fig. 41. Hang three bells and two clappers to a wire *a*, communicating with the interior coating; and three others to be fastened to the exterior coating: hook the chain *c* to the wire *a*, so as not to touch the table, and charge the jar as usual from the same wire: while it is charging, the bells hanging from *b* will ring. When the bottle is charged, remove it, and unhook the chain *q*, and let it lie on the dry table. Now touch the wire *b*, and its bells will cease, and the bells from *a* will begin to ring; then shift your finger to the wire *a*, and the bells from *b* will act, and so on, alternately, till the bottle is exhausted. In the first

case, the bells from *a* rung by electricity, propelled from the outside coating, making its way through the chains of the outside bells, by the clappers, to the middle bell; from whence the chain *d* conveyed it to the surrounding bodies. The apparatus now removed from the machine, and the chain *q* hung on the wire *a*; on *b* being touched, the propelled electricity returns in part to the outside, and repels a proportionate quantity from the inside, which rings the bells on *a* in its passage. When the knob *a* is touched, more of the positive quantity escapes, and more returns to the outside, ringing the bells in its return, and so on, alternately, till the bottle is discharged.

9th. *The effort of positive and negative quantities to meet each other, may be seen in an overcharged bottle.*

Hold the knob of a Leyden bottle, *a*, Fig. 42, to the prime conductor, while the bottle is charging, in the dark: when it is nearly charged, little flashes and corruscations will appear at *c*, and all round the edge of the outside coating: brushes will also issue from the cork of the bottle at *d*, and strive to meet the flashes at *c*; if the excitation is continued, they will meet, and a spontaneous discharge will take place. But if the uncoated part of the bottle be breathed upon, and then held to the conductor as before, the negative quantity from *c* will solicit the positive from the cork; and the positive will incline with equal affection from the cork to meet the negative, and their union may be seen at *n*; while the superquantity will fly off in a brush at *m*. If the bottle, Fig. 43 (held by its knob), be pressed against the prime conductor, while it is charging, negative corruscations will bend from the cork to meet the positive stream issuing from the outside coating, and they will visibly meet, without report, at *n*; the quantity running over, issuing out at *m*.

10th. *From what arises the beautiful corruscations among the links of a chain, when the Leyden bottle is discharged through them?*

The explosions that take place at the links of a chain are occasioned by the electrical repulsion of each other, for they, in reality, do not touch. When, therefore, a chain is tightly stretched, an electric shock will pass through it, as through a wire, without any lateral explosions.

11th. *Has electricity any weight?*

Yes: suspend a small thin glass balance on a fine point, *a*, Fig. 44; balance the hollow knob *c* with the weight *d*, and let *c* just touch the prime conductor *w*; which being electrified, the end *c* will be found to preponderate: in this case the convex parts of the knob, and conductor, must be exactly opposite, that the momentum of the aura may be equal on all sides.

12th. Transparent bodies are, in general, non-conductors of electricity; as air, glass, silk, &c. But electricity is capable of making many opaque bodies transparent by impregnating them with temporary light. If the ends of two chains, in an electric circuit, be placed at a quarter of an inch from each other, and a finger be laid at the interruption so as to touch each; when an electric shock is sent through the wires in the dark, the finger will be seen perfectly transparent. A piece of ivory laid on the interruption will be also transparent, &c.

13th. If strong shocks be sent through a glass tube filled with vitriolic acid, sulphur will appear on its surface. Is not this favourable to the old doctrine, that sulphur is but a combination of that

acid with phlogiston (or what I call fire)? For we procure the acid by burning brimstone; thereby disengaging the acid, which forms an union with water placed in leaden vessels for its reception. What effect, then, does the electricity produce when sent through this acid, but restore the fire, or phlogiston, which the sulphur lost in burning?

14th. *Electricity adds bulk and inflammability to air.*

Fill a bent tube, Fig. 45, from *a* to *b*, with heavy inflammable air, and the rest with quicksilver, inverting one end of the tube in a basin of quicksilver, and corking up the other, with a wire, *c*, through it. If strong electrical shocks are passed through the tube, the air will increase in bulk, and become so *carolified* as to burn as clear as vital air. 94.5 measures of this gas, mixed with 107.5 of oxygen gas, being fired in a close vessel, were reduced to 128.5 measures. Was not this from the escape of its fire, or electricity?

15th. A fleecy feather, suspended by a fine silken thread, and addressed to an electrified tube of glass, or stick of sealing-wax, will be attracted by the excited tube, or wax, and instantly repelled: but in that repellency, if the tube be moved round the feather, the feather will move round the tube, *and always keep the same face to the tube*, just as the moon keeps the same face towards the earth. I do by no means, however, contend here for the cause being the same.

16th. A black-lead line, on paper, is a conductor: if that line be made into an electrical circuit, after being covered with powdered resin, it will produce an amazing illumination.

17th. Electric sparks will not take place but in mediums that are bad conductors. All airs are bad conductors, except the inflammable; in this air no sparks can be taken. Does not this favour the hypothesis, that metals, water, and other bodies containing fire, that are conductors, and holding their inherent or specific electricity but loosely, derive their conducting quality from that property?

18th. *Electricity gives volatility to water, and is, perhaps, the principal agent in the rise of vapour.*

On Bennet's electrometer, Fig. 46, place a small metallic cup, *d*, with a few drops of water in it: if a live coal be dropt into it, the slips of leaf-gold will part with negative electricity; and shew that electricity was carried off from the cup and cap of the electrometer *a*, by the rising vapour; and that the slips went to the pieces of tin-foil, *c c*, to recruit their loss.

19th. The electricity of fogs and rain are well illustrated by two of the above electrometers, Fig. 47. The cap of the electrometer A, has a bent wire *m* screwed into it, having at its other end a piece of tin, *s*, soldered to it: another electrometer, B, has the metal cup *d* placed upon it (as in the last experiment), and directly beneath the tin *s*. If water from the jug *g* be poured on hot coals in the cullender *c*, the water that falls into the cup *d* will produce negative electricity in the electrometer B; and the vapour that rises against *s*, will induce a positive effect in the electrometer A. Is not electricity thus carried into a latent state like fire, or heat? Is it not evident that the steam had acquired what the water had lost? and that this is another instance that fire and electricity produce

the same effects, and, consequently, that they are but modifications of one and the same principle?

20th. This fact may be further diversified by fixing a tobacco-pipe to the cap of an electrometer, as *a*, Fig. 48. If the small end of this pipe be heated red, and fixed as in the figure; if water be poured into it, it will rise in steam against *s* (as in the last experiment), and produce positive electricity in A, and negative in B.

21st. A small bucket of water, with a capillary syphon in it, hung to the conductor, will discharge the water in drops: but when electrified, the water will diverge, flow swifter, fly about in small drops, and be luminous. Or suspend one bucket from the positive conductor, and another from the negative, with their syphons within three inches of each other; when electrified, the stream issuing from one will be attracted by the other, and form one stream, which will be luminous in the dark. If the two buckets are suspended on two positive, or two negative conductors, the streams will repel each other. Or if water be poured into a basin, placed on the prime conductor, the stream will divide into a great number of lucid drops.

A sponge, filled with water, and hung to the conductor, when electrified in the dark, will exhibit fiery rain.

The knob of a charged bottle will attract a drop of water from a basin; which drop, on the removal of the bottle, will assume a conical shape, and if brought near any conducting substance, will fly to it in luminous streams.

These experiments prove that water is separated, and dissipated into vapour by electricity, and that with uncommon rapidity.

22d. Sparks taken from electrified water, carry off a portion of that water along with them. Place a drop of water on the prime conductor, and it will deliver a very long spark, assume a conical figure (like a water-spout), and wet the body that receives the spark.

23d. Heat one end of a thick wire, so that it will make its way into a stick of sealing-wax ; the wax may then be made to project horizontally from the prime conductor, so as to be easily set on fire by a taper; if electrified whilst it is blazing, filaments, like fine threads, will dart from it the length of a yard or more, and cover a sheet of paper, held before it, with innumerable fibres like a cobweb. This is but the rise of vapour in another, but a more tenacious fluid; where by the heat of the flame, and the repulsion of electricity, the parts are thrown out into long threads.

24th. If two bottles, *a* and *b*, Fig. 49, having small tubes fixed in their corks, with each a stop-cock, be half filled with water, and the cocks be open, the mouth applied to the tubes may easily, by blowing, so condense the air within, that by its pressure on the water, fountains will take place. If these bottles, so charged, and the cocks shut, be one placed obliquely on the positive, and the other on the negative conductor, and, whilst electrifying, the cocks be opened, the fountains will lean towards each other, coalesce, and fall down in large drops, as in the figure.

These experiments strongly indicate, how positive and negative

clouds attract, unite, and mix their waters together, so as to produce drops.

25th. *How can the motion of the earth be represented by electricity?*

Fix the wire hoop, Fig. 50, *a a*, into the prime conductor *d*, and place a brass plate, *c c*, on a stand half an inch below the hoop; then lay a thin hollow glass globe, about three-fourths of an inch diameter, on the plate, and electrify the conductor: the ball will instantly begin to turn on its axis, and roll round the hoop.

26th. *May not electricity be the cause of transparency?*

Let one end of a chain be connected with a charged jar, and its other end lie on the table: place the end of another chain about half an inch from it, and place a decanter of water on these separated ends. If now the jar be discharged through these chains, in the dark, the water will appear beautifully luminous.

Does not this seem as if light lay latent in the glass and water; and was excited into visibility by the explosion made under the decanter?

27th. *How to represent words, trees, landscapes, &c. by electricity.*

Let a glass tube of about eighteen inches long, and three-fourths of an inch diameter, have small round pieces of tin-foil pasted upon it, at a small and equal distance from each other, in a screw-like form, as Fig. 51; and let this tube be inclosed in another, to protect the tin-foil: on the ends of this tube there must be cemented

brass caps like knobs. When either of these knobs are held within an inch of an electrified conductor, sparks will dart to it, and through the pieces of tin-foil, making an appearance like a spiral string of diamonds, the whole length of the tube.

2d. Short words may also be made luminous, by covering a piece of window-glass with strong copal varnish, and while wet laying on slips of tin-foil parallel to each other, at about two-tenths of an inch distance, each about the twelfth of an inch wide. When the varnish is dry, the slips may be cut in the shape of letters with the point of a sharp pen-knife, see Fig. 52. The round piece *a*, must be held near the knob of the conductor, where the fluid will enter and run to *c*, where a cross-piece of tin-foil must conduct it to *o*; from thence it will run back along the line *o g*, and so zig-zag to the thumb, which holds the glass at *w*. At every cut made with the knife, a spark will take place, and all at the same instant; so that in the dark the word will be read in diamond-like letters.

3d. Flowers, trees, landscapes, &c. may be drawn in the same way, see Fig. 53; and their beauty and brilliancy exceed all description.

28th. *How to increase the circulation of the blood, and the pulsation of the heart.*

Let the person stand on a stool with glass feet, and take hold of the conductor, or a chain connected with it; he will now become a part of the conductor himself; and when the machine is put in motion, he will feel his hair begin to spread out, and stand erect; his pulse will be accelerated; and if he should be bled in that situation, the blood would be propelled to an unusual distance;

diverge into small drops, and each drop be seen luminous in the dark. In this situation he will attract light bodies; give sparks to his neighbours wherever they touch him; charge Leyden jars; and fire warmed spirit of wine with his knuckle. To make these entertaining experiments succeed well, the insulated person should be careful that no part of his clothes touch the floor, table, or spectators; and if the stool stands on a sheet of brown paper, the insulation will be still more complete.

29th. *Electricity ignites combustible bodies, like common fire, or lightning.*

Wrap cotton wool round one of the knobs of the discharging rod, and fill the wool as full of small bruised rosin as it will hold. Discharge a jar with the rod as usual (only observe that the covered knob must touch the knob of the jar); and the rosin will be instantly in a blaze. See Fig. 56.

2d. The inflammable air pistol affords a better instance, how liable all inflammable bodies are to become ignited by electricity. This pistol is sometimes of brass, and sometimes of strong glass, as *a*, Fig. 54; *c* is a brass cap and cork, in which is inserted a glass tube *s s*, through which passes a wire, with the knob *n* on one end, and the other, turning at *g*, comes within the tenth of an inch of the brass cork; so that when the knob *n* takes a spark from the conductor, the spark is repeated at *g*, which fires the inflammable air in the body of the pistol, and drives out the cork *u*, with a strong flame, and a loud report. This pistol is charged, by being placed as Fig. 55, on a bottle containing bits of iron, nails, or filings, on which if vitriolic acid be poured, diluted with eight times its quantity of water, the inflammable gas

gas will be extricated; from its specific lightness it will rise into the pistol, and mix with the common air in it. After a minute, the cork *u*, may be put tight into it, and it is then fit to be discharged.

If instead of common air, vital air be mixed with the inflammable air, the flame and report will be vastly increased.

A drop of strong æther, corked up in the pistol an hour, will as effectually charge the pistol as the above airs.

To imitate the blowing up of a magazine of powder by lightning, have the small model of a house, as Fig. 57, the sides and roof fastened to each other by hinges. Through the board that forms the floor, have a hole for the wires *s* and *u*, to pass through; and also a cork *m*, glued on the floor, for the same wires to pass through, so that their ends may nearly meet at *x*, above the cork. On this cork must be pressed the bottle B, charged as before with inflammable air. If then the chain *y* be attached to the outside of a charged jar, and the chain *w* touch its knob, the charge will pass through the wires *s* and *u*, make an explosion at *x*, set fire to the air, which will blow up the bottle, and with it the roof of the house.

30th. *That electricity vibrates like other fluids, sometimes leaving the body possessed of it in a positive, and sometimes in a negative, state.*

If a coated pane of glass be fixed perpendicularly on a board, by the part uncoated (for two inches round its edge is always left uncoated on both sides); if one side be then suddenly touched by the knob of an exhausted bottle (i. e. charged negatively), both sides of the pane will be found in a state of want, or negatively electrified.

By the exhausted bottle touching the coating of the pane, it steals from that side of the pane a portion of its natural electricity; the other side vibrates towards it, to restore the loss, and both sides become, of course, negative.

31st. Let two small pith balls hang from the outside coating of a Leyden bottle, and its knob be slightly touched by the positive knob of a charged bottle; the balls will part with negative electricity: but if their bottle be placed on an insulated stand, and its knob again touched by the positive knob of a well-charged bottle, the balls will part with positive electricity. Why? Glass being considered as pervious to the influence of electricity (as above), the positive quantity induced on the inner coating of the insulated bottle will propel from the outside a proportional quantity, and would make that side negative as above, if the matter could get away, but being imprisoned by insulation, the influence vibrating from the in, to the outside of the glass, and there stopt; both sides remain alike positive.

A bottle charged at the negative conductor, and treated so, would have its two sides negative.

32d. Place a charged bottle on an insulating stand; bring the knob of a bottle well charged negatively, near it; and a thread will play between the two knobs; but, when the knobs touch on the stand, the thread will be first attracted, and then repelled by both: for as want was more predominant than abundance, in the two bottles, when an equilibrium was made by their contact, they become both negative. But if a finger touch the knob of the bottle, charged negatively, it instantly becomes positive, stealing with such rapidity what it wanted, that more than an equilibrium vibrates from the finger to the bottle.

33d. *The electric matter when its equilibrium is affected, or disturbed, always chuses the nearest road, and the best conductors, to restore its equality.*

I make a chain of small links into the initial of my name, Fig. 58, and attach the wire *w* to the outside of a charged jar, making a continuation of the wire *x* to touch the knob. In the dark a luminous W is seen; (for a lateral explosion takes place at every round link, from the difficulty that electric matter has of penetrating round, or flat bodies). But if the wire *n m* be laid, as in the figure, it makes a nearer road, the fire passes invisibly through it, and only is seen in half the W, *m z y*. Instead of the wire *n m*, if a piece of dry stick be laid in its place, the electric matter will take a longer circuit, rather than go through a bad conductor, it therefore rejects the stick, and passes through the whole W.

34th. Metal is a better conductor than water; as may be proved by beating a hole, with a sharp iron point, in the bottom of a three-ounce vial, Fig. 59, at *a*; in this hole must be cemented the wire *c p*. The vial is then filled carefully with water, and corked tight, and through that cork a wire passes within one-tenth of an inch of the wire *c*. The vial must be placed on a soup-plate. If now the wire, or chain, *n*, touch the outside coating of a charged large jar, and the chain *s* its knob, an explosion will take place between the two wires at *c*, that will break the vial into the most beautiful striated ramifications.

35th. The effects of an earthquake at sea, are well imitated by a loose building of boards, placed on a little boat in a basin of water: if the water be made part of an electrical circuit from a battery, the

report will be remarkably loud; the flash along the surface of the water, extremely vivid; the building will be thrown down; and a hand, put in the water, will feel a disagreeable sensation unlike a shock.

36th. Positive, and negative, electricity, mutually attract each other. Balance the round board, Fig. 9, by silk cords, on one end of a scale-beam, and connect it by a small wire to the prime conductor. If another board be placed under this, at about a foot or fifteen inches distance, when the upper board is electrified, it will draw towards the lower, and when at about an inch distance, an equilibrium will be restored, with a brilliant flash, and loud report.

37th. The earth seems the goal to which electricity has a natural tendency, whether coming from the Sun, its source, or whether disturbed in, or extracted from, the air, or earth, by machines. No sooner, therefore, is a conducting body, communicating with the earth, presented to a charged conductor, than its electricity makes an effort to seize that body; not merely because it is a conductor, but because it leads to the place where the fluid wants to discharge itself. This may be seen by presenting the same conducting substance, *insulated*, to the charged conductor, when only a small spark will be produced. So lightning strikes a tree, a house, or a thunder-rod, not because these objects are high, or in the neighbourhood of a charged cloud, but because they communicate with a part of the earth which then happens to be in a negative state, and to which the lightning would dart, though none of the above objects were in the way.

This in nowise invalidates the use of thunder-rods; as light-

ning will always take the nearest road, and the best conductors. If the lightning aims at the negative earth on which a house stands, the house will be secured by the conductor, and demolished without it.

38th. That electricity may be condensed or rarefied, like other fluids, is evident, from uniting a metal mug with the prime conductor, when it is placed on the insulating glass-footed stool: for if then a pair of pith balls, suspended by flaxen threads, be connected with the mug, and a chain be dropt into the mug by a silken thread, and all electrified, the balls will diverge; but if the chain be gently drawn out by the thread, the balls will collapse; when let down again, they will diverge, &c. shewing that the electricity is rarefied and condensed alternately, as by the extension of the chain the surface is increased, and by its contraction diminished.

This implies that we should not be surprized when we see the small effect a fog has upon the insulated pith balls, when they are suspended at the end of a fishing-rod; the electricity which assists the rise of this vapour, is too rare to affect the balls much, though they are little: but a cloud, insulated by a dry body of air underneath it, and its electricity condensed by a continual addition compressed into it by the solar stream, makes efforts to arrive at the earth, to which the utmost power, accumulated by art, is but as the stroke of a feather to that of a cannon ball.

39th. To fire gunpowder by electricity. Fix a small cartridge on a pointed wire (which should be fitted to a glass handle), and let the wire touch the ground. Present the cartridge to the knob of a charged jar, and the powder will be fired by the electric stream passing through it. Tinder, or touchwood, may be ignited by the

electric stream in that or any other manner. Certainly this fluid must be the same as fire!

40th. Fix a small ladle in the end of the conductor, and fire a piece of camphor in it: when the machine is excited, the camphor will throw out a variety of small shoots, like a vegetable. The inherent electricity of the camphor, having its natural repulsion increased by heat, carries off the glutinous resin in its flight.

41st. To perforate glass bottles. Fill the vial half full of sallad oil. Force a small wire through its cork, and bend the end that goes into the bottle, so as to approach near the side of the bottle, and to be just covered with the oil: if on the other end of this wire there be a knob, and that knob held near a charged conductor, sparks will dart from the conductor to the knob, and at the same time from the crooked end of the wire, through the bottle, to the thumb, or any other conducting body pressed opposite to the end of the bent wire. If the wire be turned to other sides of the bottle, several small holes may be perforated through the glass. Does not this arise from the tenacious nature of the oil, which, by confining and condensing the spark into a line, or point, enables it to penetrate the glass?

42d. To imitate the equal manner in which rain generally falls, put a quantity of brass dust, or filings, into a coated jar; and when it is charged, invert it, and throw some of the dust out upon a flat surface; the dust will spread itself equally upon it like rain or snow. Are not both these effects from the same cause, viz. an equal repulsion among the parts?

43d. That the coating of glass has little to do with its electric charge, is proved thus:—Lay a plate of tin or brass on your hand,

and on it a plate of glass (rather larger than the metallic plate); on the glass lay another metallic plate, and let this communicate with the prime conductor; thus the glass may be charged. By the edge of the glass disengage it from the two plates, and place two other plates in the same situation, upon and under the glass. If now one knob of the discharging rod be made to touch the under plate, and the other knob the upper plate, a discharge will ensue the same as if the first plates had remained in their place.

44th. Metals owe their conducting power to the latent fire they contain. When vitrified, they cease to conduct; when revived, or brought back into a metallic state, they conduct again.

45th. In spring, when plants begin to grow, temporary and electric clouds appear, and pour rain in small drops (attenuated by electricity). These increase in summer, as the solar stream becomes more direct; diffusing a vivifying spirit through the vegetable world, until the fruits are gathered in. This repulsive dispersion of water, by electricity, is beautifully exhibited by hanging a small metallic vessel of water on the conductor, with a capillary syphon in it: the water only *drops* from the syphon before it is electrified, but when electrified, the drops divide into numberless smaller ones, which are luminous in the dark. Steams and vapours also conduct electricity; for if the pith balls are suspended four feet above the conductor, they will not part; but if hot water, or a fresh blown-out taper, be placed on the conductor, the balls immediately separate.

Thus have I exhibited this wonderful agent in most of the lights in which it has yet been seen: and flatter myself the reader's deductions from these appearances will be similar to my own, viz.

that electricity emanates in a perfect state from the sun and fixed stars; that its particles repel each other, and fill all space; that they have an affinity to the earth and planets, but an affinity that cannot easily be gratified, because the surrounding atmospheres are in part non-conductors, being already saturated, and, of course, repellent of the electric fluid. Hence the struggles which the fluid frequently makes to get through the lower regions of our atmosphere to the earth, causing thunder, lightning, earthquakes, &c.: for a vacuum *, and the greatly rarefied air, which form the upper stratum of the atmosphere, are conductors, and receive the fluid from the sun without obstruction: it then takes possession of the clouds, and if the air below be moist, that moisture will conduct it into the earth. But when the lower air is dry, and a non-conductor, it is then obliged to use strong efforts, to accumulate in such quantities as are proportionate to the difficulties of its passage; it forsakes the clouds with terrible corruscations; they coalesce (having lost that which kept their particles asunder), and descend in heavy showers. As we have seen that many terrestrial substances, when duly impregnated and united with electricity, become permanent air; may not the atmosphere itself, formed of the finer and more volatile parts of the earth, be made fluid by their union with electricity? May it not be true that the terrestrial part of the atmosphere being powerfully attracted by the earth, will, of course, be much condensed near the earth's surface, and become more and more rare as we ascend? May not the well-known effects produced on the human constitution, and the appearance of the air, just before a thunder-storm, be occasioned by the super-saturation of the at-

* It has been affirmed, that a perfect vacuum will not conduct electricity. I have boiled quicksilver, to expel all its air, in a double, or syphon, barometer tube, of ten feet in length: when one end of it was insulated, and communicated with the conductor, the electricity passed through it with the utmost ease; and was luminous in the dark.

Fig. 1.

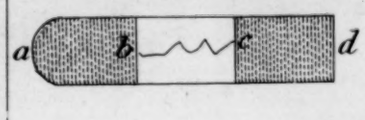


Fig. 2.



Fig. 4.



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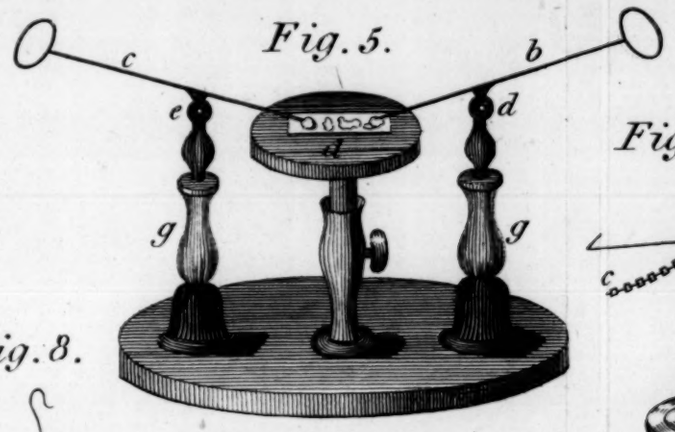


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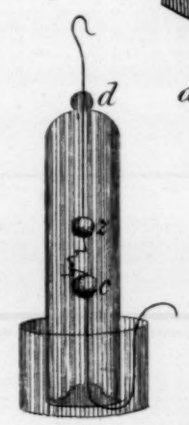


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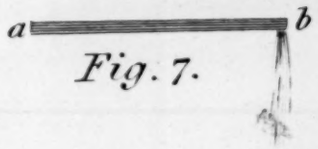


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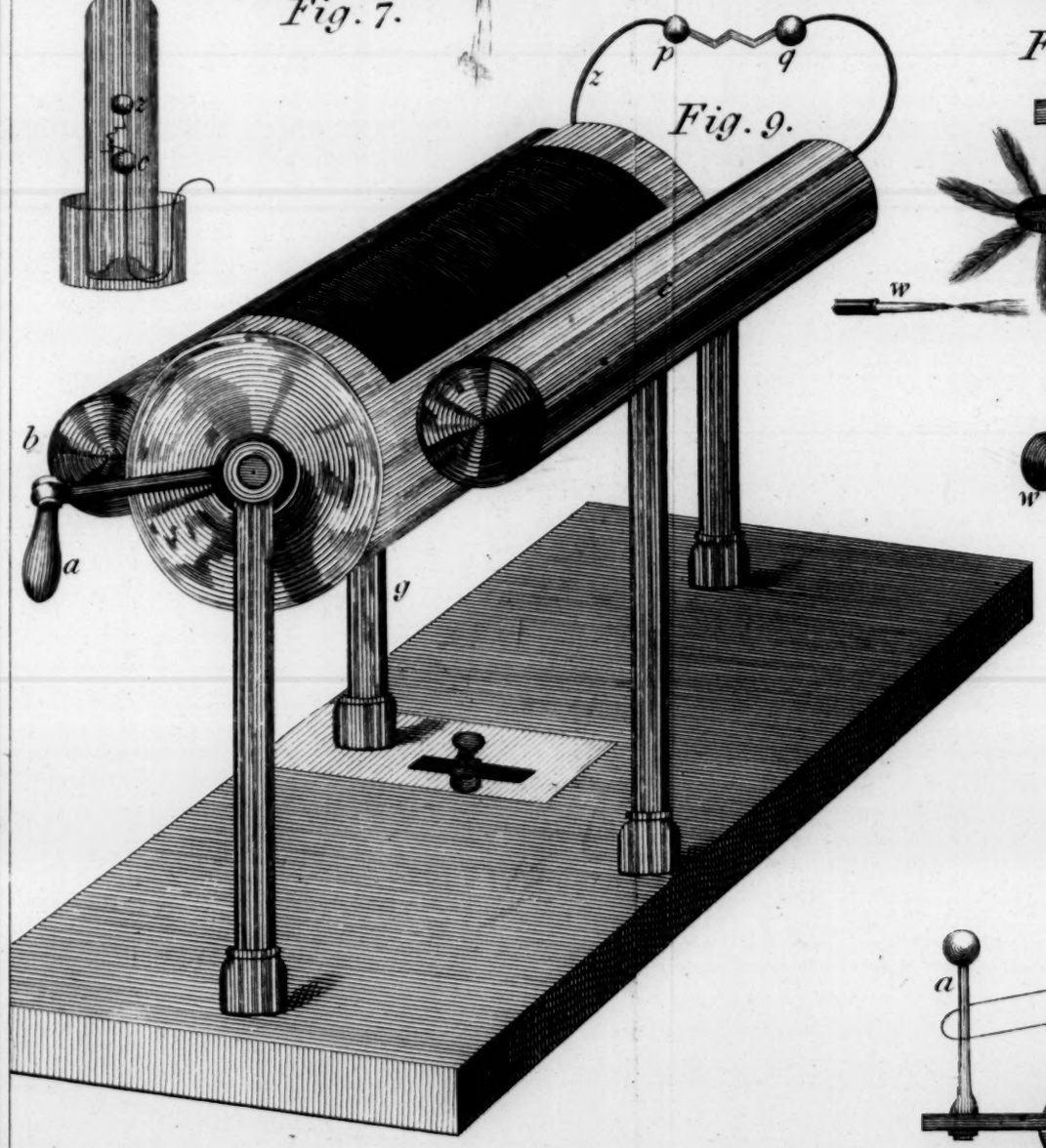
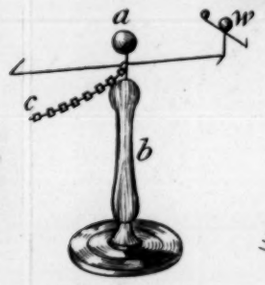


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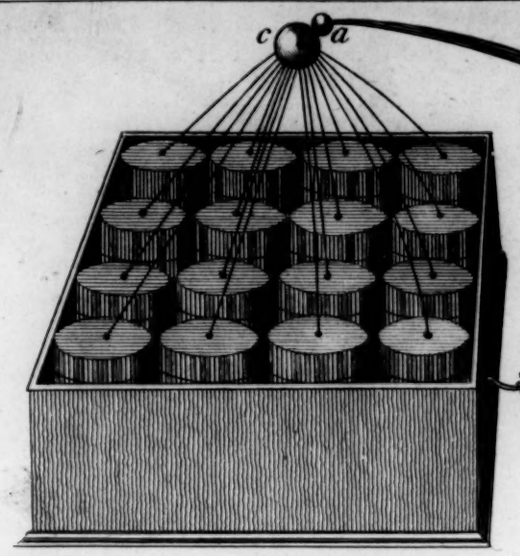


Fig. 3.



Fig. 6.

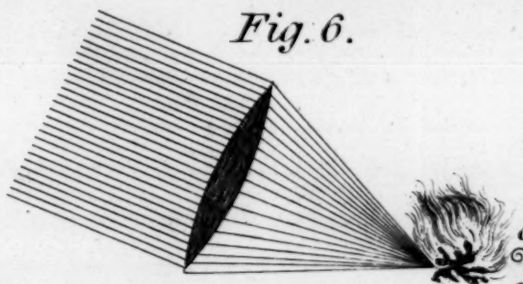
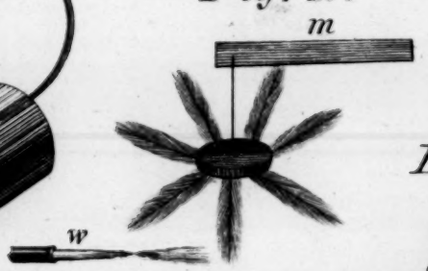


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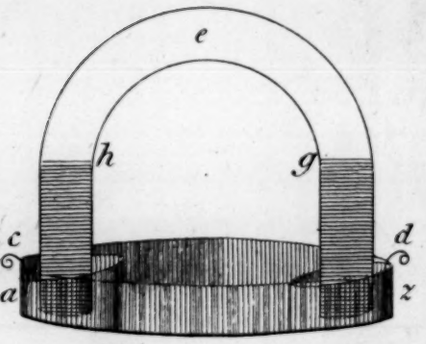


Fig. 11.



Fig. 9. N°2.

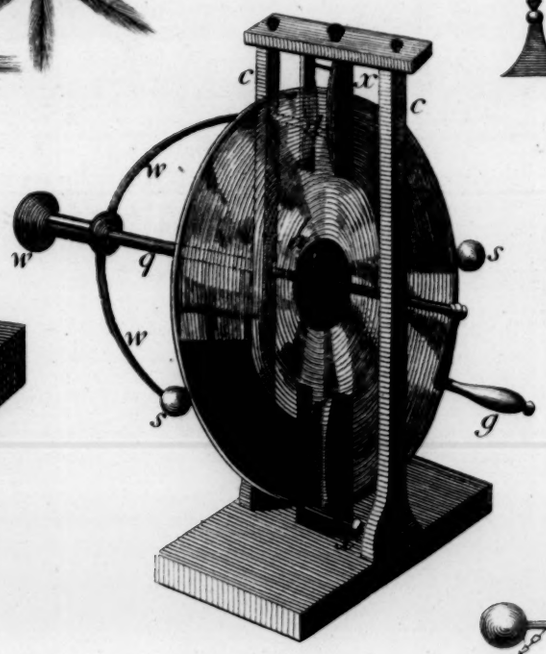
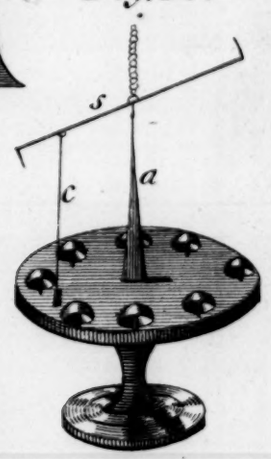
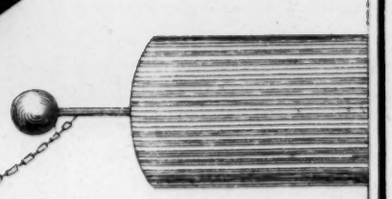


Fig. 12.





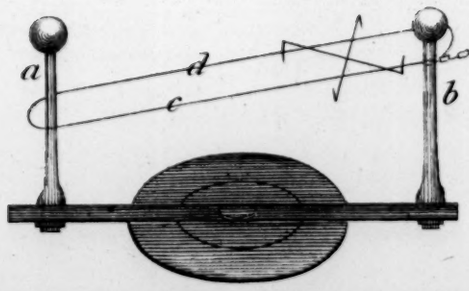


Fig. 14.

Barlow sculp.t

Fig. 15.

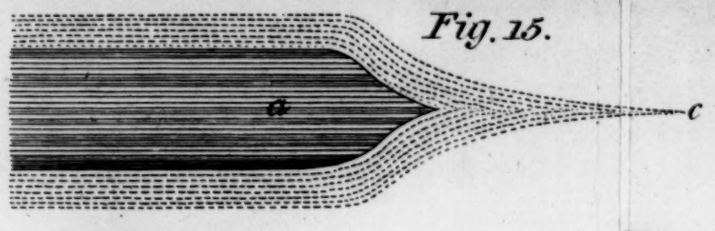


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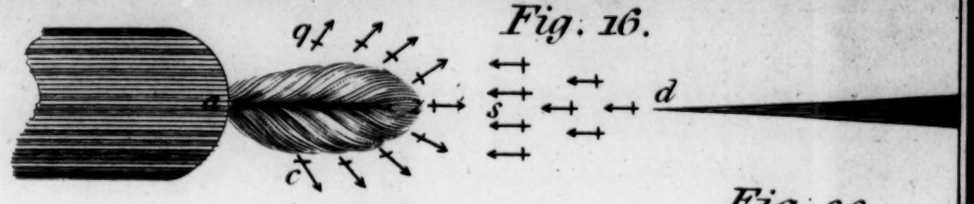


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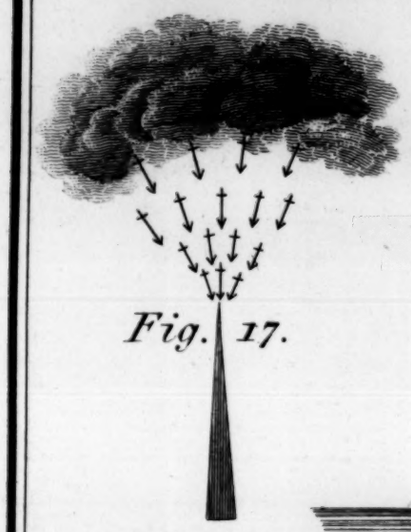


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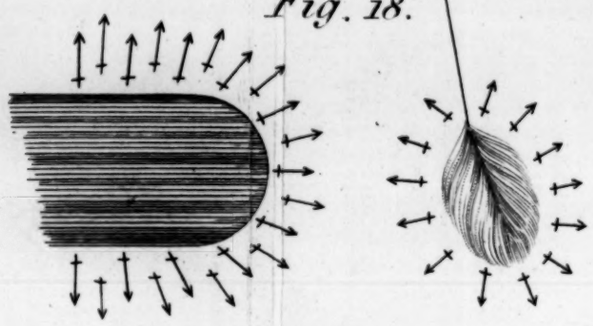


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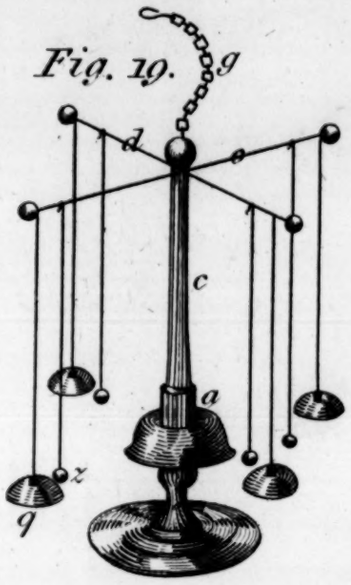


Fig. 20.



Fig. 21.



Fig. 22.

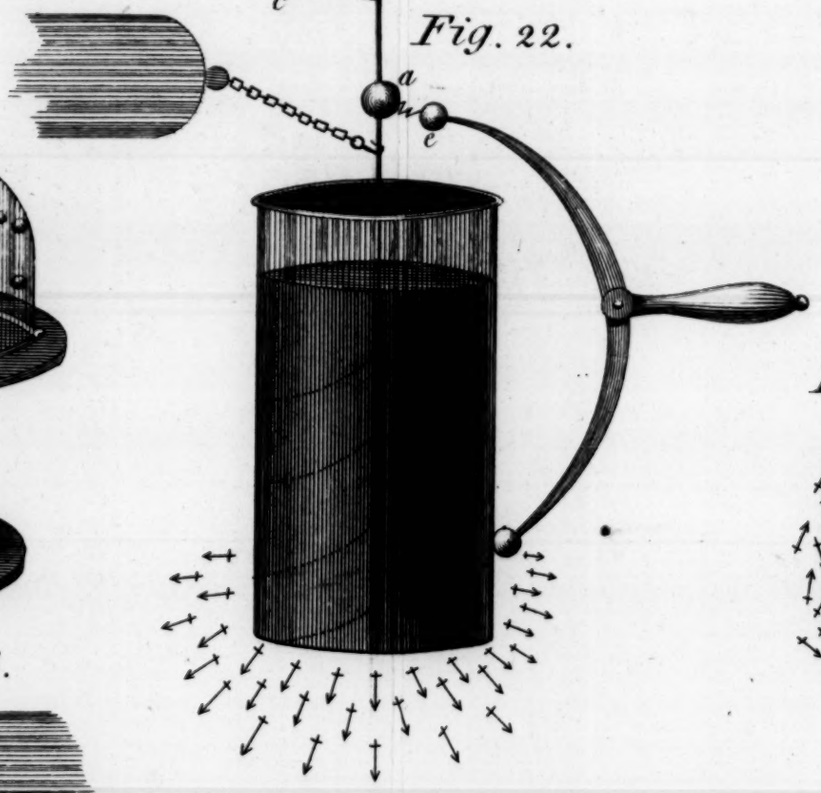


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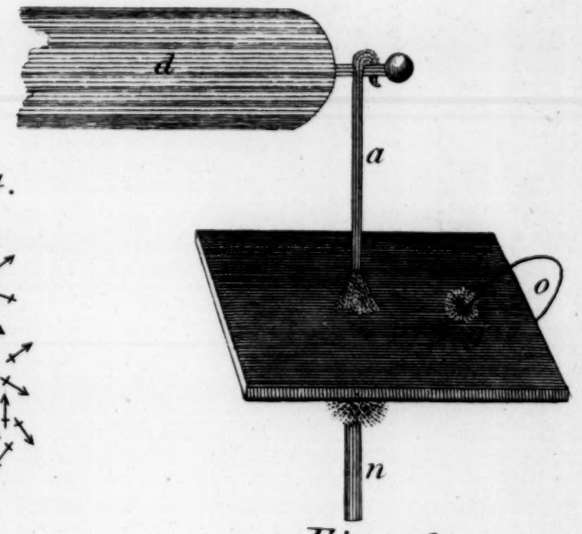


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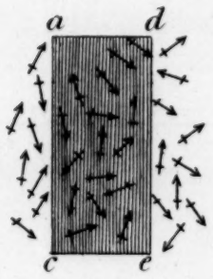


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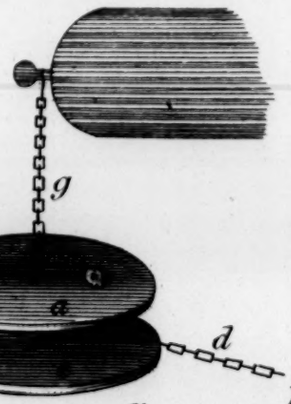


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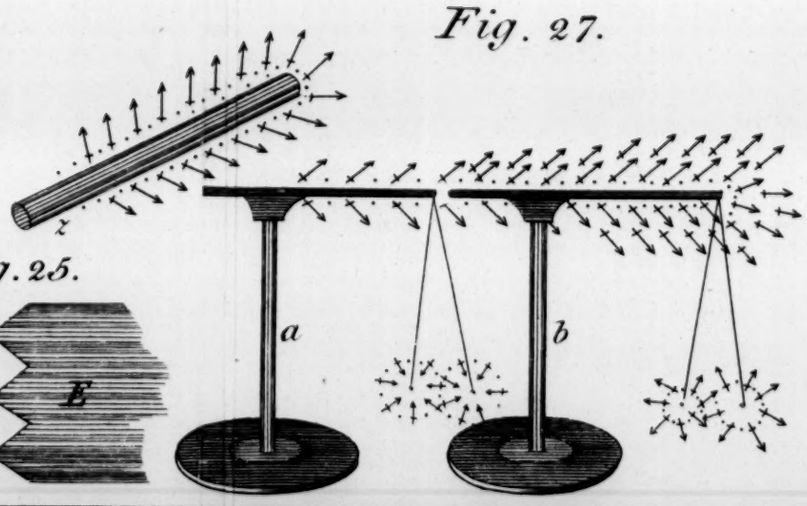


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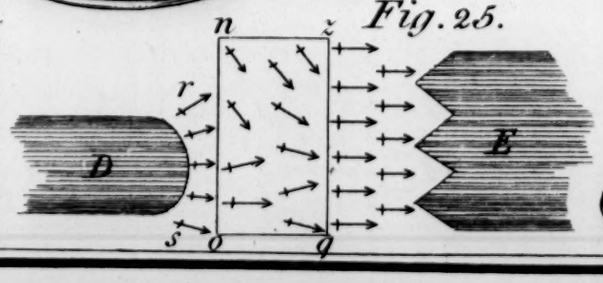
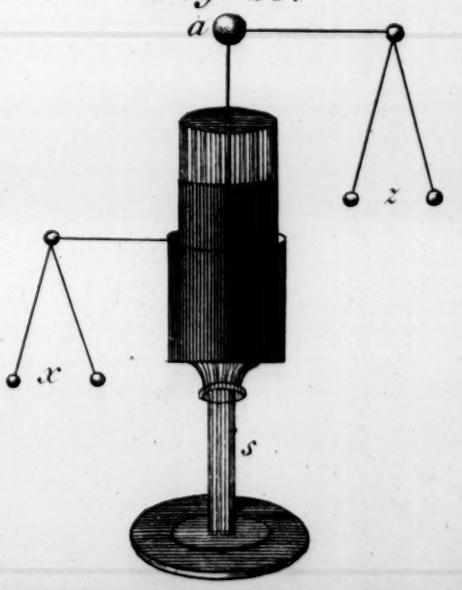


Fig. 28.



Barlow sculp.t



Fig. 29.



Fig. 30.



Fig. 31.

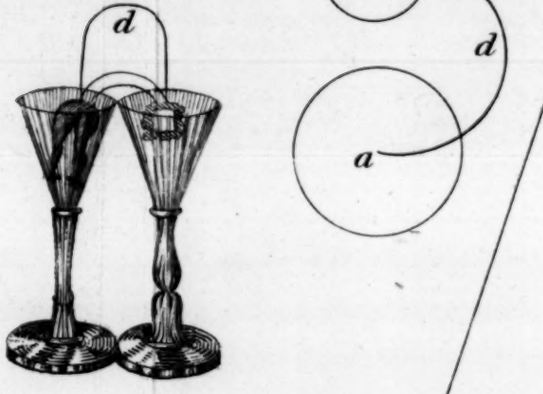


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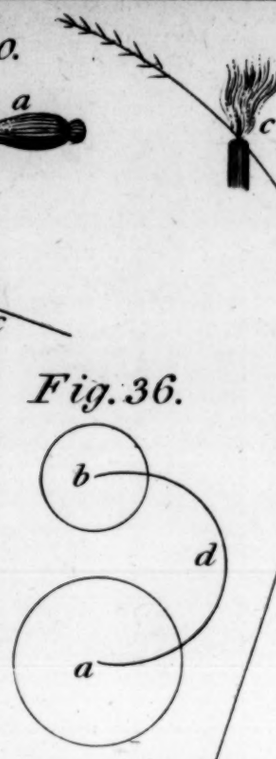


Fig. 36.



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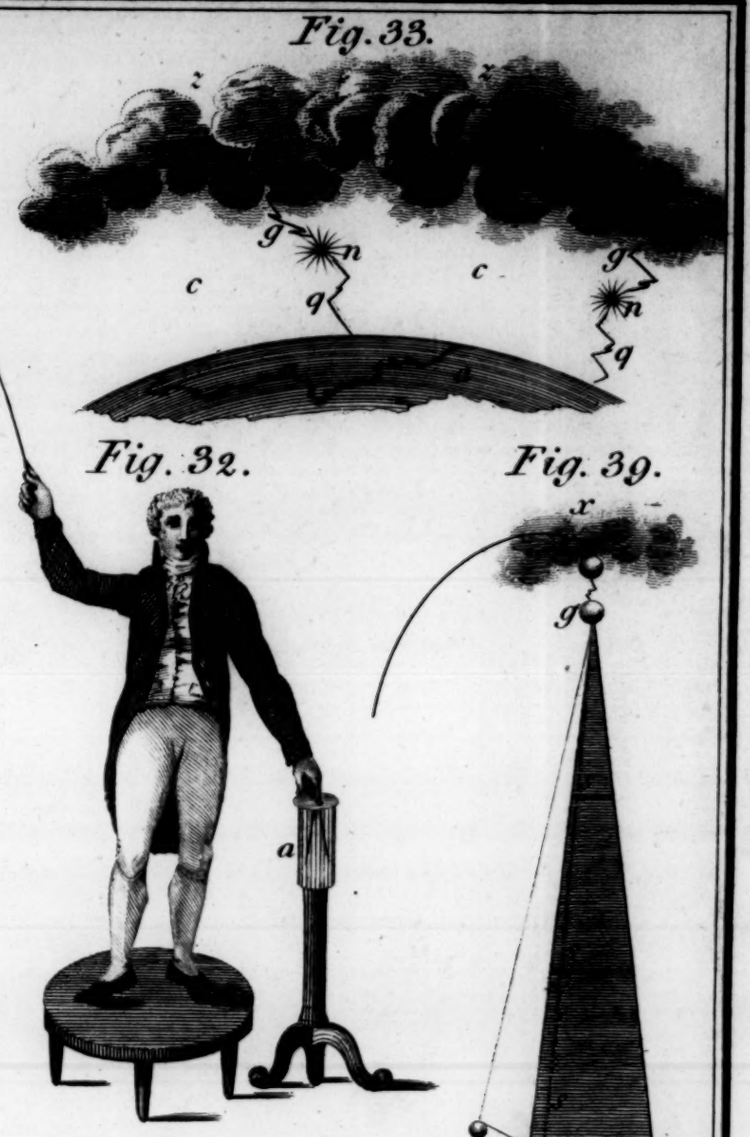


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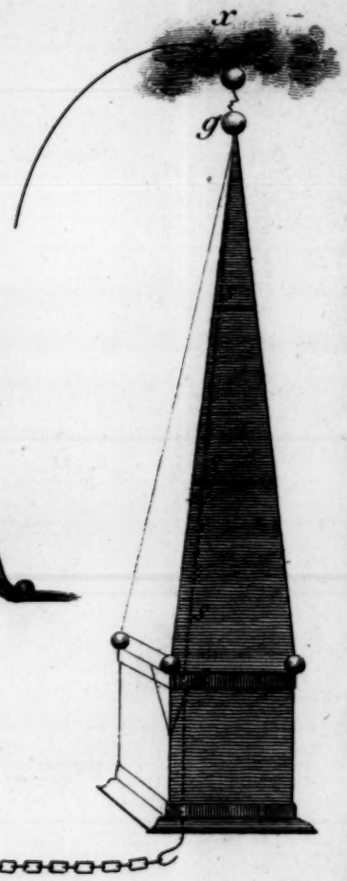


Fig. 39.



Fig. 34.

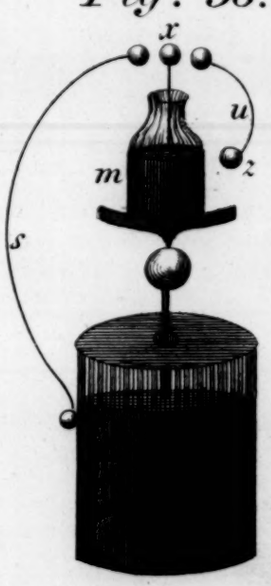


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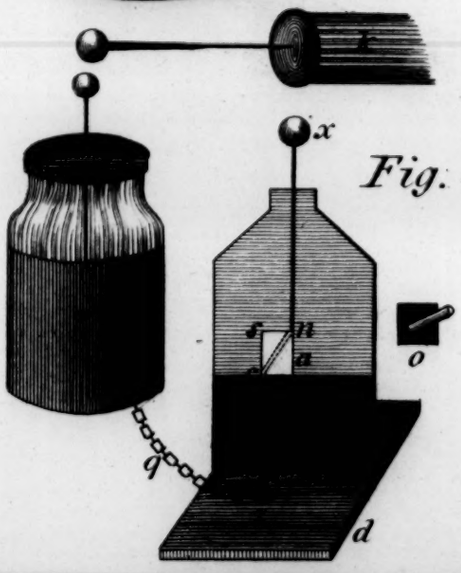


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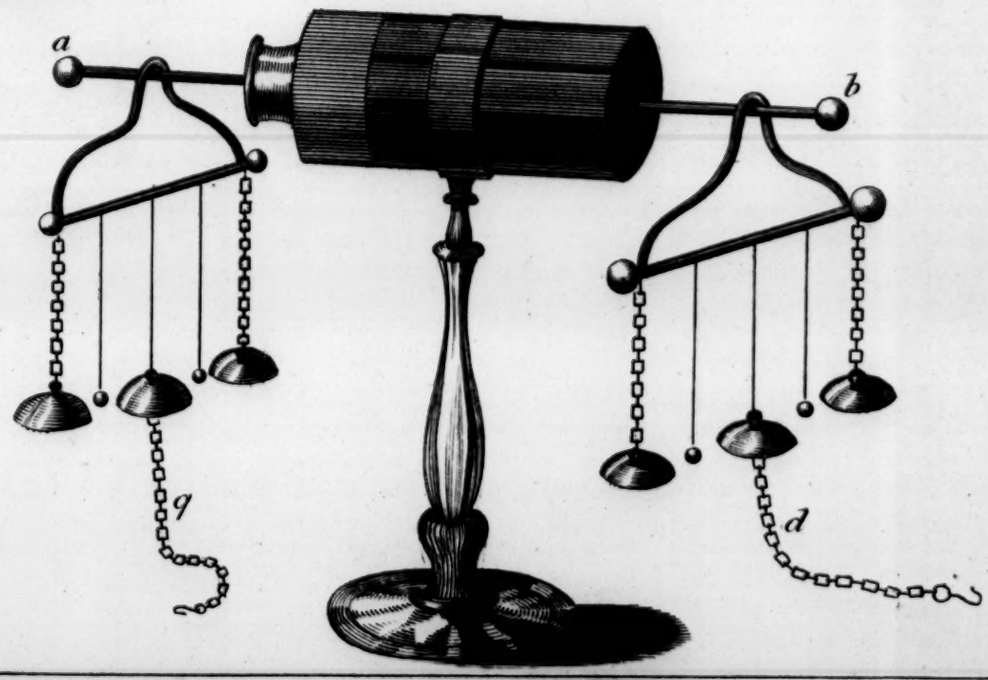


Fig. 41.

Barlow sculp.t

Fig. 42.



Fig. 43.



Fig. 44.

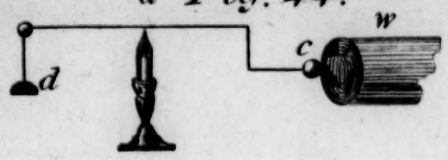


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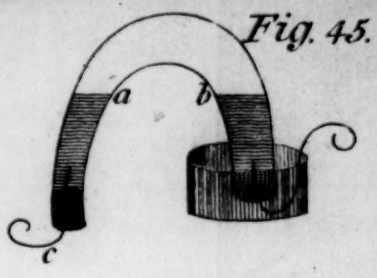


Fig. 46.



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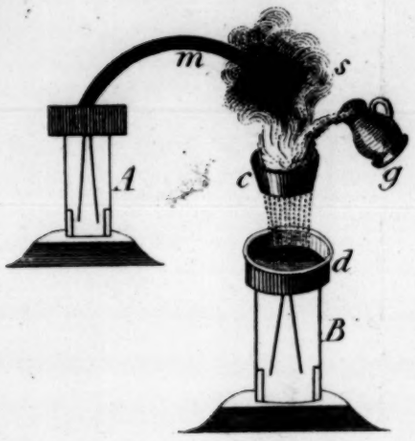


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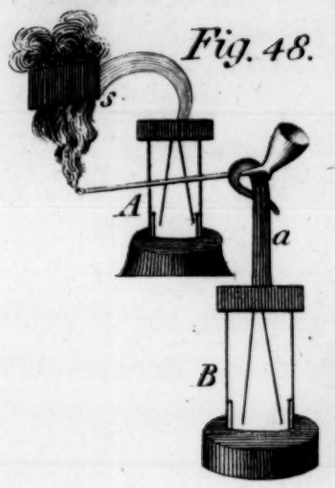


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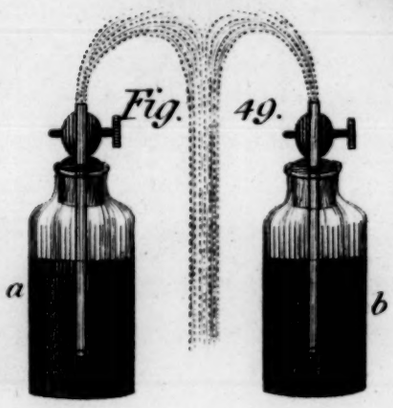


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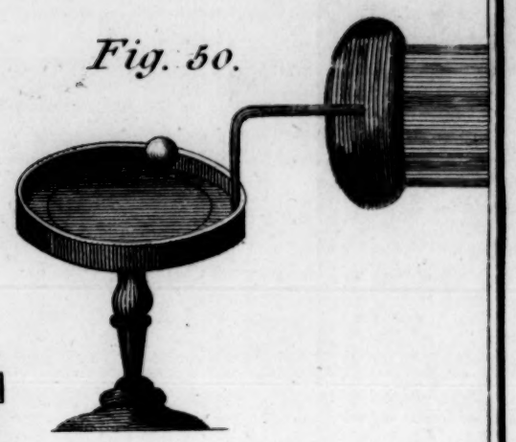


Fig. 51.



Fig. 52.

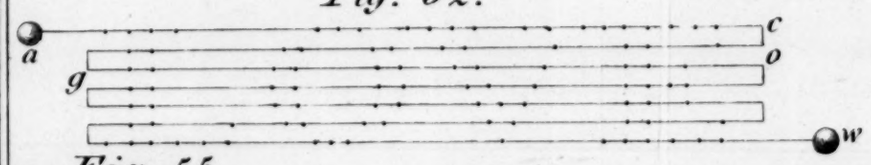


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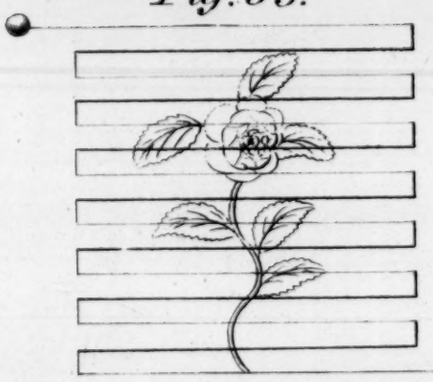


Fig. 54.



Fig. 55.



Fig. 58.

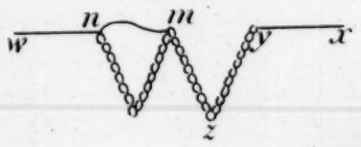


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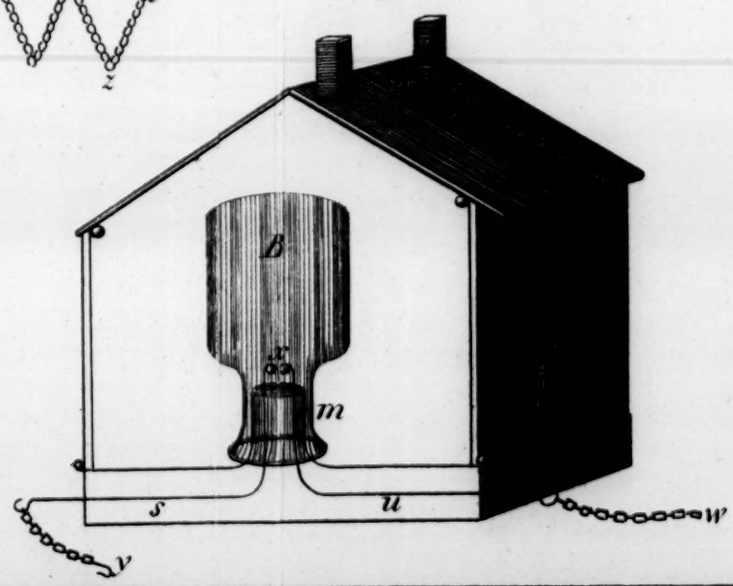


Fig. 56.



Fig. 59.

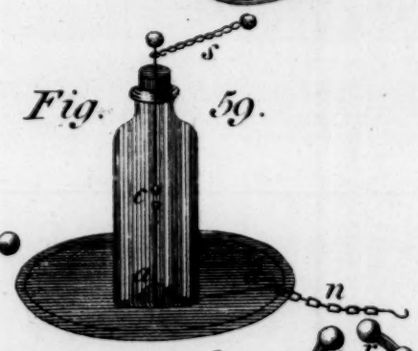
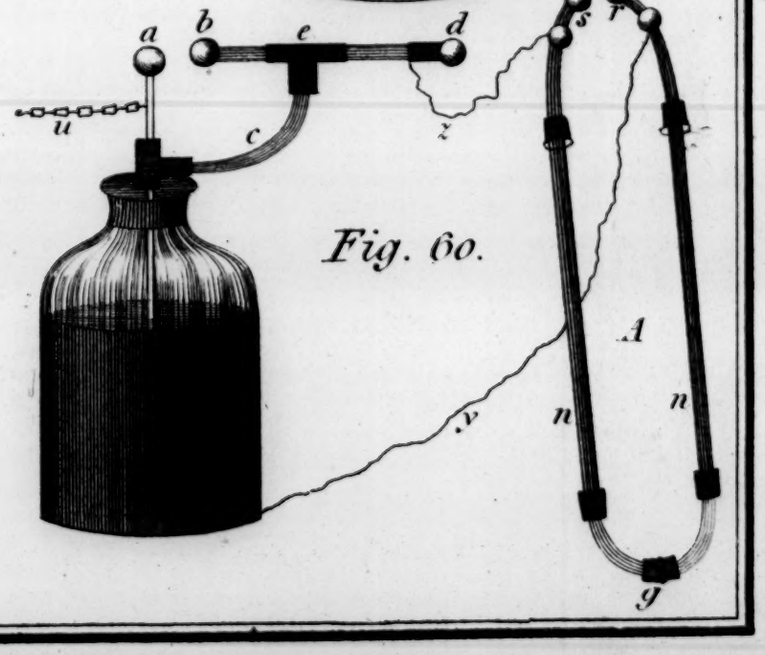


Fig. 60.



Barlow sculp.t

mosphere with electricity? And may not languor, and low spirits, in moist weather, arise from a want of electricity in the air, &c.? For easterly winds always induce disorders, and it is notorious that the air betrays less signs of electricity in those winds than in any other. Its power of exciting muscular motion in apparently dead animals, as well as of increasing the growth, invigorating the stamina, and reviving diseased vegetation, prove its relationship or affinity to the *living principle*. Though, Proteus-like, it eludes our grasp; plays with our curiosity; tempts enquiry by fallacious appearances, and attacks our weakness under so many perplexing subtilties; yet it is impossible not to believe it the soul of the material world, and the paragon of elements!

LECTURE IX.

OPTICS.

THIS branch of natural philosophy treats of light, and of the effects produced by its approach to, and passage *through*, different mediums. But before we treat of these effects, it is necessary to define what we apprehend light to be. I venture (but with some diffidence) to pronounce it DILUTED FIRE. That *attraction* and *repulsion* are the two active agents in inanimate nature, I hope has been sufficiently proved in the first lecture: that attraction is an inherent property in all matter, except fire, and would, if uncontrolled by its repulsive power, make all nature into one solid mass, was also, I hope, sufficiently evident. It seems, indeed, necessary, in the present order and fitness of things, that an antagonist principle should regulate this cohesive tendency; and that principle I conceive to be fire. This element exists in various forms, and has various names, as active fire, latent heat, sensible heat, electricity, lightning, caloric, and, lastly, light. In all those states it loses not its repulsive power; for even in its latent state, when chemically combined with bodies, and inscrutable by any of our

senses, it gives those bodies elasticity, and prevents their atoms from forming too close an union. It has been a long-received opinion, that light is but a quality, or property, of fire; but I conceive light to be fire itself, originally emanating from the sun and fixed stars, and near those bodies, no doubt, of intense heat; but being repulsed radiantly in all directions, it must grow more and more dilute; for, that intensity diminishing as the squares of the distance increase, the density of solar light at the sun must be 45,000 times greater than at the earth: so, that, at the distance of our earth, it becomes only light, united with terrestrial matter, is evident, because it can be stopt, or turned out of its way, in its course, by any opaque intervening body. That light is progressive, or rather, that it pervades all space, and is only put in motion by the sun and other luminaries, is, I think, more probable than that its individual particles travel from the sun to us in about eight minutes, according to general opinion. It is true, we see the eclipses of Jupiter's satellites 16′ 24″ sooner when the earth is in that part of its orbit nearest to the planet, than when it is in that part the most distant from the planet; but that does not imply that the individual particles of light fly from Jupiter to our eyes in 16′ 24″: it certainly proves the effect to be progressive; for, if we were to conceive a line of particles of light reaching from Jupiter to the eye, and that Jupiter was the agent that put those particles into motion; as those particles are repulsive and elastic, the effect of Jupiter's impulse must be progressive; it could not be the same as if a solid rod were to reach from Jupiter to the eye; for then the impression at one end of the rod would be felt at the same instant at the other.

We also see the fixed stars a little different in their situation in

one part of our orbit to what we do in another: this is called the aberration of light, and may be understood by Fig. 2; where *a b* represents a portion of the earth's orbit, *c* the star. As light is progressive, and supposed to travel from *c* to *b*, while the earth travels from *a* to *b*, the star will be first seen along the line *a c* (suppose through a tube); now if a tube be kept parallel to its first position, when the earth arrives at *e*, the star will be seen in the line *e m*; for while the earth travels from *a* to *e*, light has travelled from *c* to *x*, and when the earth arrives at *g*, the star will be seen along *n w*; for the particles of light impelling one another, will have their sensible effect at *z*; so at *n* it would be seen along the line *n o*. Or if *c* was considered as a falling drop of rain, just entering a tube *a c*, and the tube was kept in the same parallel position while the person who carried it ran from *a* to *n*; the drop, in that time, would fall from *c* to *n*, through the tube, without touching its sides.

Having thus proved that light is progressive, emanating from the sun and fixed stars, we may also conceive that its particles repel, and fly at a great distance from, each other. This may be proved by the ease with which the rays of light cross in the focus of a large lens; or by placing a number of candles in a line before a small hole in a sheet of pasteboard, when a sheet of white paper on the contrary side of the pasteboard will have as many specks upon it as there are candles; shewing that light can issue from each candle through a hole made with a pin without the least justling or inconvenience. If the particles of light were not, therefore, small beyond all conception, flying with such a velocity, they must come into the eye like shot out of a gun, instead of that imperceptible manner in which

they impinge upon the optic nerve. Yet small as they are (and capable of passing through transparent mediums with little impediment to their motion), their extreme velocity gives them a momentum: for, hang a small steel wire by a magnet, and let the focus of a large lens touch the wire, and it will put the wire into motion. A small wire, with a piece of thin copper fixed to one end, was balanced on the point of a fine needle, and inclosed in a glass case, to prevent any motion that might be in the air: the focus of a large concave mirror was then directed upon the piece of copper, which it put immediately into motion, and was computed to have struck it with a force equal to the 1800 millionth part of a grain (according to Mr. Mitchell), on a square foot of the earth's surface. This momentum is also proved by its tearing in pieces, and dispersing, the hardest and most compact bodies, when exposed in the focus of a large lens. The momentum of common light is not perceived by our sense of feeling, and scarcely by sight; for as the particles move at a great distance from one another, the impression of one particle is lost before another succeeds.

The tail of a comet is observed always to point *from* the sun. Is it not more than probable, that it is the stream, or current, of light issuing from the sun that causes it thus to point?

Some comets, indeed, have been observed to have had the end of the train a little bent. Does not this favour the hypothesis of light issuing from every fixed star as a sun? That currents of light meet in infinite space, mix, assimilate, and unite with one another? That stronger currents absorb, or turn back, the weaker? That the light which misses the planets of each sun is not lost or wasted, but, assembling with other light, is kept in perpetual mo-

tion? That light near each sun must be more dense than when at a distance, and, therefore, that the tail of a comet may be in two currents at once, a stronger and a weaker, and thence derive the inflexion at its remoter end?

Light is dormant till put into action by a luminous body, or by heat; so in the night the particles of light are stagnant (except they are put into motion by candles, or other combustibles, in a state of ignition), but assume their wonted motion again on the rising of the sun. So fire in chemical union with wood, metals, or any combustible body, lies dormant, or latent, till forced into action by communicated heat; and coals, wood, candles, &c. will not ignite till they are previously heated by a body already in a state of ignition: for fire impels fire, as light impels light; and affords another proof of the identity of light and fire.

The momentum, or moving force, of light being thus established, and, consequently, its materiality, let us trace it through different media, and it will be found also to have its affinities like all other matter. I admit a ray of light through a hole half an inch in diameter into a dark room: if the air through which it passes be of uniform density, it proceeds through it in a straight line; but if I let the ray fall obliquely on a polished cube or square of glass, as Fig. 3, it will be bent towards the centre of the glass in its passage into, as well as out of it. Does not this prove that light is, in a small degree, the slave of attraction, as well as all other matter? If the ray be suffered to fall perpendicularly on the glass, it passes straight through without any inflection; because it is attracted nearly in every direction alike. If the same ray strike the inside of an empty bowl placed on the floor, and the place be marked; it will be found, when water is poured into the bowl, that

the ray will not fall on the same place, but nearer to that where the ray enters the room. Hence also an oar appears crooked in the water. The property which transparent mediums have of attracting light out of its rectilinear direction in air, is called refraction, and this effect is in proportion to the density, or specific gravity, of the medium; i. e. water does not bend a ray so much as glass, nor glass so much as a diamond, &c.

The law of this refraction may be explained by Fig. 1, where *b n r* is to represent the surface of water, and *a n* a ray of light entering the water at *n*, where it will be attracted out of the straight line *a n c*, into the direction *n d*. Now it can evidently be seen that the angle of incidence, *a n b*, is greater than the angle of refraction *c n d*, the sines of which always bear a proportion to one another; i. e. the sine of incidence, *a b*, is greater than the sine of refraction, *d c*, in glass, out of air, in the proportion of three to two; out of air into water in that of four to three, &c.

If a ray fall obliquely on a plate of glass, or on a body of glass whose sides are parallel, with the same angle it entered it, with the same angle it will leave it on the opposite side, Fig. 3.

From this property are derived the use and application of all kinds of optical lenses; and an explanation of various optical deceptions.

1st. I place a cubical box, *s*, Fig. 4, in such a direction that I cannot see the patch *e*. If a glass cube be then put into the box, I shall see the patch at *a*; *for we see every thing in the direction of that line in which the rays approach us last.* This is an axiom in Optics, and may be exemplified by placing several mirrors before a candle, as Fig. 5; though rays issue from the candle in every direction,

we will take only one, viz. *a b* (to keep the figure simple); this ray is reflected to the mirror *c*, from thence to the mirror *d*, from *d* to *e*, and from *e* to the eye *s*. But the mind transferring every object seen along that line in which the rays came to the eye last, the reflected lines are put, as it were, to the end of the last line, *e s*, and the candle is seen at *k*, at the distance of all the reflected lines put into one straight one. So the ray *e c*, Fig. 4, being refracted in its passage out of glass into air, into the direction *c r*, the eye perceives it at *a*, nearly one-third of the depth of the box from its bottom.

By intuition, or instinct, the eye cannot judge of distances in air or water, or any transparent medium. We learn to discriminate distances by experience alone. A child will grasp at the moon with the same avidity, as at a candle within his reach; and a blind person brought to sight, believes every object he sees to be touching his eyes. Many a school-boy has lost his life, by supposing the bottom of a clear river to be within his depth (as the bottom will appear one-fourth nearer the surface, than it really is); and we are worse judges of distances in water, than in air. A fish looks larger in water, than when taken out of it. The distortion of objects seen through a crooked pane of glass, in a window, arises from its unequal refraction of the rays that pass through it: and a shilling put in the bottom of a punch bowl, Fig. 6, could not be seen along the line *a b*; but if the bowl be filled with water, the eye will see the shilling along the line *a c*. Various and important are the effects of this law, in the order and economy of nature. The sun is seen before he comes to the horizon in a morning, and after he sinks beneath it in an evening, by the refractive power of the atmosphere; and hence we never see sun, moon, or stars, in the places where they really are; except they are in the zenith, or right over head; in

which case their light is so equally attracted in every horizontal direction, that it passes through the atmosphere, without any refraction. This increasing refraction, from the zenith to the horizon, causes much trouble in astronomical and nautical calculations, in taking the real altitudes of the heavenly bodies: which may be better understood by inspecting Fig. 16, plate 2, which represents half our globe, and its atmosphere. A person standing at *a*, would see the sun rise at *b*, when it was, in reality, only at *c* (rather more than half a degree beneath the horizon), the line from *d* to *a*, a little bent; because the density, and refractive power of the lower part of the atmosphere, is greater than the upper, the air growing gradually rarer, or more thin, the higher we ascend in it.

If a person at *a*, had the sun, *e*, in his zenith, he would see him where he really is: for his rays coming perpendicularly through the atmosphere, would be equally attracted in all directions, and therefore suffer no inflection. But about two in the afternoon he would see him at *i*, though, in reality, he was at *k*, thirty-three seconds lower than his apparent situation. At about four in the afternoon he would see him at *m*, with greater error: for now he is at *n*, one minute and thirty-eight seconds from his apparent situation. But at six o'clock (we will suppose) he sets, and will then be seen at *o*, though he is at that time at *p*, thirty-three minutes below the horizon. These phænomena arise from the refractive powers of the atmosphere, and the obliquity with which the rays fall on it; because we see every object we look at along that line in which the rays from it came to us last: so that I see *k* along *a r*; *n*, along *a s*; and *p*, along the line *a t*.

Art has turned the refractive power of glass to many important

uses: spectacles, though the simplest, are not wanting in eminence; as they prolong the enjoyment of one of our most valuable senses to a date that we should not possess from nature. They may be made plano-convex, double convex, or concave. The plano-convex lens is plain on one side, and a portion of a sphere, or globe, on the other, see No. 1, Fig. 17. If parallel rays fall on this lens, they will be so refracted in their passage through it, as to unite in a focus at *b*, see Fig. 7, on the opposite side of a sphere, of which the convex side of the lens may be conceived as a part. The ray, *a b*, falling perpendicularly on the lens, and being equally attracted by it, passes straight through without refraction.

The double convex lens, No. 2, Fig. 17, has double the effect of the last, for it assembles parallel rays in a focus at the centre of the sphere of its convexity. The magnifying power of both these lenses depends on this convexity; for the angle of vision increases in proportion as the sphere of convexity grows less. Thus the angle *c d e*, Fig. 9, is larger than the angle *n o p*, Fig. 8, and would magnify any object seen through it more. For every object may be conceived to be big or little, according to the angle it forms in the eye. The pen *c*, Fig. 10, would appear to the inexperienced eye as tall as the tree *d*; because it makes as great an angle at the eye; and a small ball held near the eye will cover the sun. The moon is known to be a mere speck in comparison of the sun; yet she appears as large, and can cover his whole disk in an eclipse, because she is so much nearer to the earth as to form as large an angle at the eye.

In looking at the cross *a c*, Fig. 11, I see it under the angle

a d c: but if I place the lens *b* between my eye and the cross, the rays which painted the image on my optic nerve before, viz. *a d* and *c d*, will be refracted in the directions *n r* and *o p*; and, of course, be useless to the eye. But the rays *a s* and *c o* falling on the outer part of the lens, will (according to a former explanation) be refracted to the eye in the directions *s d* and *t d*, and form the angle of vision *s d t*. Hence, as every thing is seen along that line in which the rays come to the eye, the top of the cross will be seen along the line *d e*, and the bottom along the line *d m*; consequently the lens has increased the natural angle of vision *a d c* to *e d m*. In this figure, rays are only taken from the two ends of the object, that it may not be crouded and confused with lines; but it must be understood, that rays issue from every part of the object (if it be illumined by the sun, or a candle), and are magnified equally with the two ends. The magnifying power of spectacles, of refracting telescopes, microscopes, &c. depends on this principle.

The small arrow, Fig. 12, is represented with rays issuing from its two ends in all directions; but it is only those rays which fall on the lens *a c* that the lens can affect; the other rays are dispersed radiantly, and would meet the eye on all sides: hence the reason why bodies can be seen on all sides, either by direct or reflected light. Direct light is that which issues immediately from the sun, or any luminous body; reflected light is that which is rejected or thrown back by polished, white, or light-coloured bodies, on the sides of objects on which direct light cannot fall: and hence the reason why parts that are in shade are yet visible. But reflected light (even from an highly-polished metallic mirror) is not quite half so vivid as direct light. If the small arrow, Fig. 12, be strongly enlightened, a white screen at *d* will exhibit the picture of the

arrow enlarged and inverted; for the pencil *a n c* will unite at *r*; and the pencil *a o c* will unite at *s*, and so will all the intermediate parts of the arrow. Rays that diverge or spread in their approach to a convex lens, will converge proportionally to a focus beyond it: solar rays may be considered as parallel, and converge beyond the lens to the *real* focus, as at *a*, Fig. 8.

Hence an eye placed at *u*, or still nearer the lens, Fig. 12, would see the small arrow upright; but placed at *d*, the dart would appear to be inverted on the retina, or optic nerve, as on the screen *r s*. For all objects of sight, duly enlightened, have their pictures painted on the optic nerve, when the eye is turned to them, as on the screen *r s*; from which picture we learn to judge of the length, breadth, shape, colour, &c. of all objects we look at.

Not only on the retina, or optic nerve of the eye, are objects painted inverted, for a convex lens produces the same effect on a sheet of paper held in its focus, as *e r*, Fig. 18. The cross, *a b*, is supposed to be sufficiently illumined to push its light through the lens *c d*; but we shall only take a pencil from *a*, and another from *b*, that the figure be not confused with lines. The ray *a c* becomes influenced by the attraction of the lens, and, agreeable to the laws of refraction (already explained), is drawn towards the centre of the lens, into the direction *c r*. Could the ray *a c* have gone forward to *e*, the cross would have been pictured upright; but to have done this, Nature must have invented a new law, different from every attraction we meet with in her works. For all attractions are towards the mass, or centre, of bodies: of course the lens, attracting towards its centre, inflects the ray *a c* in the direction *c r*; and the ray *b d* in the direction *d e*. So that the pencil *a c d* unites

at *r*, and the pencil *b c d* at *e*; and so does the light from every other part of the cross, and, of course, the whole picture is inverted.

Rays are supposed to come parallel from the sun, or any very distant object: a convex lens, held perpendicularly to such light, will unite it in its real focus; for converging rays will throw that focus farther, and diverging rays nearer. In Fig. 13, the parallel rays *a a* come to a focus at *c*. The diverging rays *b b* unite at *d*, and the converging rays *s s* unite at *g*. So when objects are near the lens, their pictures on an opposite screen will be large; but the pictures will grow less, as the object removes from the lens. Fig. 19, the object *a* produces the picture A. The object *b* produces B, and the same object at *c* produces C, &c. When convex lenses are very large, their focus produces on opaque bodies the most intense heat producible by art. One of three feet diameter (having its focus condensed by another smaller lens) fused twenty grains of gold in four seconds; twenty grains of silver in three seconds; ten grains of platina in three seconds; ten grains of cast-iron in three seconds; a topaz of three grains in forty-five seconds; crystal pebble, seven grains, in six seconds; flint, ten grains, in thirty seconds, &c.

Lenses, therefore, for optical purposes are, Fig. 17, No. 1, plano-convex; 2, double convex; 3, plano-concave; 4, double concave; 5, meniscus; 6, the prism. For the same reason that a convex lens increases the angle of vision, and magnifies objects, the concave lens diminishes them. For the thick part of this lens, Fig. 17, No. 3 and 4, is on its outside, therefore its attractive and refractive powers are not as in the convex lens, tending towards a centre, but towards a circumference. Hence the concave lens dis-

perses the rays, or spreads them out radiantly; perfectly agreeing with the forementioned laws of refraction, by the obliquity with which they fall on the glass. Hence also their diminishing power. For if *a b*, Fig. 20, represent an arrow seen by the eye along the lines *c a* and *d b*, and if then I interpose the concave lens D between my eye and the object, the line *a c* will be bent towards *g*, and the line *b d* bent towards *k*, and, of course, both become useless to the eye. But the ray *a o*, suffering a similar refraction, will be bent towards the eye in the line *o c*; and the ray *b r* will be sent to the eye in the direction *r d*. Now as every point of an object is seen along that line in which the ray approaches to the eye last, the point of the arrow is seen along the line *c o* at *n*; and the hilt of the arrow along the line *d r* at *m*; diminished and distant.

The meniscus glass is like the crystal of a common watch. It neither magnifies nor diminishes objects seen through it. Sometimes its inner and outward surfaces are portions of different spheres.

The focal length of any convex lens is easily found, by holding its axis in a line to the sun; the burning point, or the smallest speck, is its focus; the distance of that focus from the lens is its focal length.

The size of an image may be increased at pleasure by bringing the object nearer the focus of the convex lens.

When the eye and an object are fixt, if a concave lens move from one to the other, the size of the object will increase to the middle, and then decrease again.

The brightness of an image increases with the size of a convex

lens, but decreases in distinctness; for only the rays which fall on the centre of the lens converge to a point; those towards the edge disperse as in a prism, and make the object confused. Hence reading-glasses have their edges ground off, or covered with black horn.

When rays of light pass near to any body, so as to come within the sphere of its attraction, or repulsion, a partial refraction, or reflection, takes place: all the colours being bent either *towards* or *from* the body; but some more than others, though at the same distance; so that coloured streaks appear both within the shadow and on the outside of it; the nearest is inflected most. If *n*, Fig. 21, be a hair crossing a ray of light, little wider than itself, it will repel the nearest *a c* and *a b* to the greatest distance; and if the edges of two knives approach each other, a ray passing between them through a hole, made with a pin, in sheet-lead, this repulsive power will be still more evidently seen.

But of all optical lenses, the prism is the most important and instructive; by this triangular piece of glass are we enabled to analyze a ray of light, and account for the cause of colours. If a ray be let through a hole, of half an inch diameter, into a room, lined with black cloth, and perfectly impervious to all light, except what passes through the hole, and a prism intersect it as *a*, Fig. 22, the ray will cease to go forward in the direction *c d*; it will be decomposed, and exhibit on a white screen a beautiful spectrum, consisting of seven primitive colours, viz. red, orange, yellow, green, blue, indigo, and violet. The edges of the adjoining colours seem to melt into, or mix with, one another; which makes the line of distinction between one colour and another not well defined, except the experiment be made with great accuracy. This definition

of limits was, however, effected by Sir Isaac Newton; in which he found that the width of each colour was agreeable to these numbers, viz. red 11, orange 8, yellow 14, green 17, blue 17, indigo 11, and violet 22. This is supposing the length of the spectrum of colours to be divided into 100 parts. Fig. 23 will more particularly explain this. If the prism be held perpendicularly to the ray, and turned, the spectrum will be seen to rise above and fall below a place where it will seem inclined to stop; when fixed at that place, the spectrum will be perfect, and if measured, and divided into 100 parts, each part will bear a proportion to another, as the spectrum *a b*, Fig. 23, which intervals answer to the intervals of the diatonic scale of music; i. e. if A L be a musical string divided into two equal parts, the half A A will be an octave to the whole string; and if that half be divided into 100 parts, twenty-two of those parts will make the interval between A and B, and answer to the breadth of the violet colour. Eleven of the same parts will make the interval between B and C, &c. &c. These intervals may also be represented by the aliquot parts of the string A L, viz. A B is eight-ninths of its length, and forms the boundary of the violet colour. A C makes five-sixths of its length, making the limit of the indigo. A D is three-fourths of the line A L, and forms the division between the blue and green colours, &c.

This wonderful conformity between musical notes, and the refrangibility of light, seems as if our scale in the major key had its foundation in nature. The analogy is double: there are but seven notes in music, exclusive of interposing semitones; and there are only seven primitive colours in nature; and these colours suffer a refraction in their passage through the prism, that marks the proportional distance at which a performer should place his fingers on the finger-board of his violin.

This varied refrangibility we apprehend arises from the difference of size, or density, in the particles of light. We find the red part of light capable of struggling through thick and resisting mediums, when all the other colours are stopt. The sun, therefore, appears red when seen through a fog. Distant light even transmitted through blue or green glass, always appears red; and lamps at a distance, seen through the smoke of a long street, are red, while those that are near, are white. Dr. Halley's hand appeared red in the water, when he was in a divers'-bell, at the bottom of the sea. This colour always makes the strongest impression on the eye; and a blind man imagined it to be like the sound of a trumpet. Are not these proofs that red light consists of the largest sized particles of light; which, therefore, have a momentum, capable of pushing through such resisting mediums as stop, or absorb, the rest: accordingly, the red part of light, in passing through the prism, is the least refrangible of any other; and the violet the most, as consisting of the smallest sized particles. If any colour be separated from the spectrum by another prism, it will not change, but retain its colour; which shews that the colour is in the ray of light, and not in the bodies on which the colour falls. If the red ray be separated, as Fig. 27, and made to fall on a blue coth, it will still be red, though the blue may mix a little with it. So if the prism be raised through the orange, yellow, green, &c. in succession, the colours will still be orange, yellow, green, &c. shewing that the colour on any body is not the colour of that body, but of the rays it reflects. Why is my coat black? because that hue has so strong a chemical affinity to light, universally, that it absorbs the greatest part of the light that falls upon it, and reflecting little, makes a blank on the nerve of the eye, and we call it black.

In transferring fire from one body to another, heat is always

produced (vide Chemistry), so black cloth exposed to the sun, imbibes his rays with so strong an affinity, that, to a wearer, it is warmer in winter, and hotter in summer than cloth of any other colour. A piece of black and a piece of white marble, laid on snow in the sun, demonstrates this: for the black marble will become hot, and melt the snow; while the white marble, rejecting, or throwing off all the rays of light, receives little or no heat. Hence we say that neither black, nor white, are colours; for the first absorbs all, and the second rejects all. And hence the coolness of white muslins, and their propriety as summer clothing.

That heat should be produced by the absorption of all the rays of light that fall on the black body, is strongly in favour of light having a chemical affinity to certain bodies, and chemical rejection to others. It unites with avidity with black bodies, and flies from white. May not the colour of all bodies arise, therefore, from this chemical affinity, and this chemical rejection? It is true, black bodies can be seen, though they are considered as absorbing all the light that falls upon them; for some light will be reflected from the outside fibres, or inequalities of the body; and the quick absorption of such bodies, and the vibrations made among their particles, by that absorption, will occasion heat, till the union is perfected. And when such bodies are heated, so as to be disposed to let go their latent light, in the character of flame, if they are not black, they universally turn so, before they ignite into flame. This paper is white, yet very combustible: we must not suppose that it rejects *all* the rays that fall upon it, any more than that black absorbs all; enough will be retained to give it ignition, when air (the other ingredient of inflammability) has such convenient access to its single leaves. But a quire of it, made compact (as in Clay's manufactory), will burn no better than a stone. Is not flame, therefore, solar light let

loose by combustion? and is not the colour of bodies a disposition in them to absorb some of the seven primitive colours, and reject others? Why is this cloth green? Is there any thing inconsistent with the known laws of nature, in conceiving, that it absorbs the red, the orange, the yellow, the blue and violet, and reflects the green, which, meeting the eye, impresses that colour upon the optic nerve? We are taught by an ingenious experimenter, that we see colours by transmitted, not by reflected, light: that light first passes through the colouring particles, on the surface of bodies; that it there meets with a white surface, which reflects it back again, through the colouring particles, and that so tinctured it comes to the eye. Some nice observations are made, that a fibre of green wool, cotton, or silk, is white underneath this coat of colour. But how this can be proved, or why light should be at the trouble of penetrating the hard surface of a piece of yellow marble *twice*, I leave to those minute philosophers, who amuse themselves with puerile subtilties. It is an excellent rule in philosophizing, not to admit of more causes than will account for the phænomena. Why may not light have its affinities, as well as the more gross bodies of the chemists? Do not all metals absorb it? Are not the oxyds, or calces of metals, revived by it?

In a dark room, lined with black cloth, if there be a contrivance by which a hand may be put out into the light, without letting light in, these experiments may be made:—Put a letter into the light, and keep it exposed to it about a minute; when it is drawn into the dark room, it will be as visible as the paper you now read from: but it will instantly begin to emit, or repel, the light, and grow darker and darker, till it becomes as invisible as any thing in the room.

2d. Lay a key on the letter, and put both into the light as before. When they are drawn into the room, the paper will be luminous as before; but the key will be quite invisible, and if taken off the paper, will leave its shape upon it, as if marked with ink. Are not the absorption of light by the metal, and the rejection of it by the white paper, made visible by these experiments? Light may be forced out of iron prismatically, by gradually increasing heat. Lay a thin slip of iron on a red-hot plate of the same metal; the slip will first turn of a violet colour; as it becomes hotter it will turn blue; hotter still, and it will assume a greenish-yellow hue; if the heat increase it becomes red; but if that heat be made intense, all the rays of light are forced out at once, and it becomes a white heat, as workmen call it; for the mixture of the seven primitive rays together, universally produces a white. Steel is frequently heated to the blue colour, and there stopt; hence we have blue steel trinkets, tools, furniture, &c. for the surface of the steel at that heat, acquires a disposition not only to emit blue light, but to have that disposition fixt by cooling, so as to reflect blue light long after. That iron is capable of supersaturating itself with light, is evident from the copious manner in which it emits it, when burnt in vital air. For if a piece of small iron wire, or a watch spring, have a piece of tinder lighted on its end, and then be plunged into a quart of vital air, the metal will burn with a white light too intense for the eye to look at. (Vide Chemistry.)

That light enters into the texture of bodies, and becomes a constituent part of them, all nature demonstrates. How else are we to conceive, that the quantity of light poured on the earth by the sun since the creation, has been disposed of? That light is but fire in a greatly diluted or rarefied state, is proved by condensing it by a large lens, or concave mirror; the focus of which ignites com-

bustible bodies, melts the hardest metals, and vitrifies bricks, stones, &c. and this, independently of air; for the same effects take place in vacuo. Even by its natural condensation in the character of lightning, it produces the same effects; and forests, in the torrid zone, have been set on fire by the sun's direct rays, without either natural or artificial condensation. Can we, therefore, doubt, *That all fire is originally derived from the sun?* By the repulsive energy of fire, the solar atoms are impelled through space; and more particularly through that part of space which surrounds the plane of the sun's equator. For as the sun revolves on his axis in about twenty-five of our days, it is natural to suppose that the centrifugal velocity of his equatorial parts must give additional velocity to the particles thrown off from thence; and diffuse them through the zodiac (or that space through which the earth and planets revolve) with a force that may, perhaps, be one cause of both the annual and diurnal motion of the planets. (But of this hereafter). Though a greater quantity of light may thus be thrown off, and diffused through the immediate track of the planets, than can impinge upon them; so that much of that light must miss them, and fly seemingly waste through infinite space.—Yet as we find the fixed stars turn on their axes, in like manner as our sun; that their light comes progressively to us like the sun's light; and that they have many other attributes in common with our sun; can we doubt that they are Suns themselves, diffusing light around them, and giving vegetation to various worlds? How grand is the idea of light issuing from thousands of suns; and meeting in different directions, without justling or impediment; (for by mirrors we can make portions of solar light meet one another in every direction, without causing the least obstruction). We may see hence that light is not lost or wasted; that it may travel from one sun to another, and that in

all directions; or meeting with more powerful light, may be absorbed into its motion, and turned into a contrary direction to that in which it was originally projected. For, from the manner in which the sun's rays put out a common fire, we see how the greater momentum of solar light will overcome and turn back the weaker rays of culinary light: and by placing twenty candles in a row, before a small hole in a sheet of pasteboard, twenty specks will be made on a sheet of paper on the opposite side: shewing that the particles of light fly at a great distance from each other, and, therefore, cross one another without justling or inconvenience. Need we be surprized that we perceive no waste in the sun? that his size is not diminished? or that his light and heat have lost nothing of their original energy? For the small quantity of light absorbed by the planets, can rob him of little; and even this light is perpetually let loose, and thrown back into the general mass of light, by combustion, electricity, volcanos, &c.

It is a known fact, that all lands rise above their former common level by cultivation; for, by loosening their texture, it gives freer admission to light and air; and how necessary light is to vegetation, is too well known to be enlarged upon: vegetables consist principally of light; which, by affinity, becomes incorporated with the earth, air, and water, which form the other parts. For when vegetables are decomposed by combustion, we find that the quantity of earth, water, or air, contained in them, is inconsiderable when compared to the bulk of the plants. It follows that the light let loose by the combustion, formed the greatest part of their mass. Though vegetables may seem to rot on the surface of the earth, they still retain much of their latent light: they raise the surface, where they rot, above its usual level; and render much of that

surface combustible. Nay, though those vegetables become animal food, and deposit a portion of their latent fire in the stomach, a large portion of it returns to the earth, and contributes to raise its surface.

Hence the general surface of the earth, as well as its vegetable produce, is universally combustible, or impregnated with solar light, which lies in a latent and insensible state; but which may be called into an active and sensible state by combustion, fermentation, friction, or stronger affinities.

Trees, moss, turf, and even the earth's surface itself, are combustible to the depth of a few inches; below which it may be ignited, or made red-hot, by heat, but not to emit flame, or solar light. Pit-coal may seem an exception; for it is got many fathoms below the surface. If we fill a retort with bruised coal, and distil it in the usual way, there first comes over a little phlegm, or water, of an acid smell and taste; then a kind of oil, like turpentine; after which a thick tar: and a black coal remains behind. Fill a similar retort with saw-dust, or wood to be charred in iron retorts, and the same ingredients will be produced. May not pit-coal, therefore, be antediluvian forests, turf-moss, and the fat of fish, covered by earth in the general deluge? and in burning this fossil, may we not let out light that has been imprisoned five thousand years? This is not a jest. Light may be imprisoned (as every one knows) for hundreds of years in dry wood; and when developed, or let loose by combustion, may blaze more vividly than when cut down: because, when growing, it was united with much water; and water, both in its natural and gasseous state, has been shewn to have a peculiar affinity to solar light, to carry it into, and retain it in, a latent state.

In the process of charring wood, it must be observed, that a heap of wood is covered up under a coat of turf, and then ignited; air-holes are made through the turf, to let in just so much air as may keep alive the ignition, without suffering it to blaze out. This being kept up for eight or ten days, the light inherent in the wood becomes concentrated in the calx of the wood. Or, if wood be roasted in a close iron vessel, with apertures for letting out a vapour of water and an acid, fire is still better concentrated. Bergman proves, that 99 parts out of a 100 in charcoal, are of the inflammable principle, or what I call fire. Now, neither fire nor any inflammable principle can be proved to be anywise concerned in the growth of wood, *except light be diluted fire:* light in combustion is let out from charcoal in such abundance, that but the one-hundredth part of an ash or earth remains.

Dryness in the air is exhibited by those plants that have large and thin leaves, such as the gourd, the beet, the petasite in the fields, and the cacalia in the mountains; they droop and incline on the approach of dry and stormy weather; but assume an appearance of vigour, when the dews and rain have restored elasticity to their fibres: so that the dry air relaxing and emptying their vessels, gives them the power of absorbing the carbonic rain-water that succeeds.

Air, as before observed, is necessary to inflammation. No flame can take place, or exist, without the vital part of air. Why? The air near the earth is filled with terrestrial particles, which arrest solar fire in its passage through it (for air, water, glass, &c. that are *really* transparent, suffer light to pass through them, even in its most condensed state, without imparting any heat to them). The lower part of the atmosphere, therefore, arrest-

ing a portion of light or fire in its passage through it, and that light being also heated by reflected light from the earth's surface, they together assist the ignition of combustible bodies, to a certain height in the atmosphere. For rarefied air will not support flame; and, therefore, as the atmosphere grows gradually thinner as we ascend in it, there must be a height where flame could not exist. This, however, must be at a great elevation, because we have seen fiery meteors at the height of many miles. Perfectly transparent air being thus incapable of receiving heat from solar light, it is the opaque earth that gives heat to the lower regions of the atmosphere; and hence the increasing coldness as we ascend in it.

Perhaps it is the conflict between incident and reflected light, that assists in giving heat to the earth's surface, and the air in contact with it; for rays made to cross one another, always produce additional heat at the place of their meeting. The variety of smooth surfaces among stones and pebbles by which light is reflected; the chemical rejection of some bodies to light, by which it is thrown back; and the bending, or refraction, which light suffers in passing through transparent substances, must mix and compound the rays in such a variety and multitude of focuses, as to give great heat to the earth's surface, and the air in contact with it. This is powerfully exemplified among mountains on a hot day, where their several sides reflect light to one place: in that place the heat is intolerably scorching! The sandy deserts of Barbary afford another proof, as well as the rocks and sands of all other countries.

The instinctive tendency which all living vegetables have towards light, shews how much it is necessary to their very existence. Close wooded trees have only leaves on their outsides next to the

light, as cedars, laurels, bays, pines, box, &c.; and, where a tree is incumbered with others on one side, it will grow bushy and luxuriant on the other; tending always towards light. Geraniums, growing in a window, turn their flowers towards the light, even near a fire: and plants, growing in the dark, will find a hole (if there be one) through which they will push into the light; but, if they are doomed to darkness, they turn pale, and die. It is much the same with land animals: horses, dogs, sheep, cattle, &c. pine away, when long confined in darkness: and in the human species, miners, weavers, prisoners, &c. are always pale and sickly; and, indeed, all whose professions are carried on within doors. Owls, and insects that fly by night, are of a whitish colour; so are grubs and worms. As vegetables become blanched and colourless when shut out or covered from the light, it follows, that the colour of leaves and flowers is derived from light. Why is grass green? Is it not that the organization of plants disposes them to unite chemically with all the rays which fall upon them, except the green part of that light, which they chemically reject, and throw off in all directions; so that when those meet the eye, a green colour is impressed or painted on the retina, or optic nerve? As light is an assemblage of seven different sized particles, and these of different colours, viz. red, orange, yellow, green, blue, indigo, and violet, as shewn by the prism, is it not agreeable to the same analogy, that differently organized flowers should have different affinities, some rejecting one colour, and some another; nay, that one and the same leaf of a flower shall, in parts, be of so different a texture, as to reflect red, blue, violet, &c. light? The tricoloured violet, or heart's-ease flower, has one part of each leaf yellow, and another violet. Examining these with the deeper magnifying powers of a microscope, in a strong light, it will be found that the texture of the yellow and violet parts is very different. In like manner the red and white

roses will be found to differ in their texture: and that flowers of the same colour, but of different kinds, will be found to have a similar texture. The feathers of the butterfly's wing may be seen by a deep magnifier, to be of different shape and contexture in their different colours, &c. &c. Is it not, therefore, a disposition in the surface of bodies to reject this or that coloured light, by which they may be said to be of this or that colour? and do not all paints or dyes merely qualify the surfaces of bodies to reject this or that coloured light? That reflection is occasioned by a repulsion taking place at some distance from the surface of the reflecting body, no way militates against this doctrine; for fire or light is the very principle of repulsion, and no doubt acts, or has an influence, at a distance from the surface of bodies, particularly when warm. Sir Isaac Newton seems to have entertained a similar idea, in the query, where he says, " Are not gross bodies and light convertible into one another? and may not bodies receive much of their activity from the particles of light that enter into their composition? May we not, therefore, conceive that plants and trees derive their different colours from the affinities and rejections they have to particular coloured light? That the indigo leaves absorb blue light; the lignum nephriticum red light: and that infusions of these woods only suffer blue and red light to pass through them? For, take a square bottle filled with a red transparent liquor, and another of the same shape filled with a blue transparent liquor, and hold them up before the light, and nothing can be seen through them: for the red bottle stops the blue light; and the blue bottle stops the red light; so that the two held together become as opaque as a piece of coal. If a growing red rose be placed near, and in the light of, a decanter filled with a blue transparent liquor, and the

decanter just fill a hole in the shutter of a dark room, the rose in a few days will acquire a bluish tint.

Many transparent mediums reflect one colour, and transmit another, as is the case with the infusion of lignum nephriticum, which suffers the red light to pass through it, and rejects the green. So leaf gold held before the light, is green; by reflected light, yellow.

It is more than probable, that in hot climates (or in hot weather in our own), vegetables become supersaturated with light, and emit a portion of it; for heat increases its repulsive property: but in this radiant emanation, a quantity of the essential oil of the plant will be carried off along with it, and produce those aromatic odours, so agreeable to the sense.

This is strongly exemplified in pieces of odoriferous bodies floating on water: the emanation is so strong, that from the reaction of the water, the pieces will whirl round as if they were alive. Thin pieces of camphor will always be curled up when shaved off by a knife; and falling on water, will only touch it in one part; for the oiliness of the gum, and its lightness, will make it repel the water, so as scarcely to touch it. From the parts of the camphor elevated above the water, the odoriferous stream is so strong, that, pushing against the water, it is put into a circular motion, which will continue for some hours, if the surface of the water be kept clean, by laying filtering paper upon it; for the smallest drop of oil stops the motion at once.

The resins and volatile oil of plants are derived from light. Some plants contain this ſtrong smelling matter in their young branches; ſome in their leaves and buds; some in the calyx of their flowers; and some in their barks. But without light, neither colour, taste, smell, combustibility, growth, flavour of fruit, or this resinous principle, would have any existence! Hence it is, that, in hot climates, where light is more pure, resinous or aromatic substances more particularly abound. Light also qualifies plants to emit vital air: for freſh leaves put into an inverted glass vessel full of water, will produce a pint of this air in a few days, if exposed to the sun's light. It disengages vital air also from the nitric acid, the oxygenated muriatic acid, &c. &c. and reduces the oxyds or calces of gold, silver, copper, lead, &c. to their metallic or reguline state.

" Organization, sensation, spontaneous motion, and life, exist only at the surface of the earth, and in places exposed to the light." We might affirm " that the flame of Prometheus's torch was the expreſſion of a philosophical truth which did not escape the ancients. Without light, nature would be lifeless. A benevolent God, by producing light, has spread organization, sensation, and thought, over the surface of the earth." Lavoisier.

But to return to the refrangibility of light in the priſm, drops of rain, &c. It is certainly evident, from former experiments, that the refrangibility of different coloured light, bears an invariable proportion to the size of its particles: i. e. that the red part of light, consisting of the largest size, has therefore the greatest momentum (or moving force), and, of courſe, is the least liable to be turned out of its way by the prism, or any other attracting medium: that the orange is the next in size and refrangi-

bility; and so on to the violet, which consists of the smallest sized particles, and is, therefore, the most turned out of its direction. In other words, the refrangibility is inversely as the size of the particles. That these colours are inherent in their different sized particles, and incapable of being changed into any other, will be proved by Fig. 28; where a ray of light is intercepted by the prism *n*, and throws the colours on the black screen *m*, in which there is a small hole *a*, that will admit the green part of the spectrum to pass through. If that green ray be received by the prism *o*, it will be green on the screen *e*: if that screen was of wood, stone, or metal, of any colour whatever; or if *e* was a mirror, and reflected the ray to *d*, still the green colour would remain unchanged and unchangeable. If the hole in the screen *m* was shifted, so as to receive the red, the blue, or any other part of the spectrum, it would be found that neither refraction nor reflection would alter the colour. Colour, therefore, is essentially in the rays of light, and not in the bodies that either reflect or refract them. Now, if the lens *b c* be held perpendicularly to the diverging prismatic rays, they will be brought to a focus at *g*, and that focus will be white; shewing that the mixture of the seven colours together produces a white. If oil colours on a pallet were mixt together in the proportions as Fig. 23, viz. violet as 22, indigo as 11, blue as 17, green 17, yellow 14, orange 8, and red 11, they would produce white. So if a circle, Fig. 24, was painted in its compartments, agreeably to the divisions, Fig. 23, viz. 22, 11, 17, 17, 23, 8, 24, and put into a swift circular motion, the whole circle would, in strong light, appear white; for its colours would, by that motion, be mixt as on a painter's pallet. Why, therefore, is this paper white? because it reflects the greatest part of all the rays that fall upon it. Why is snow white? Every flake of snow being but an assemblage of frozen globules of water sticking together, it reflects and refracts the light that falls upon

it in innumerable directions, so as to mix it as intimately together, as in the whirling ſpectrum; and, of necessity, to produce a white image in the eye. A cascade is white for the same reason.

Catoptrics.

This branch of Optics treats of light, as reflected from variouſly figured poliſhed mirrors or bodies. How light is thrown back from the surface of bodies must be first enquired into. The reaſons for its being reflected by a kind of chemical rejection, or want of affinity, have been pretty copiously given. But as such an opinion as that of the great Newton ought to be precedent to that of an humble admirer of his philosophy, without title or academical honours, he begs leave to give that the first place, in speaking upon the subject of Catoptrics.

If the edge of a knife approach, very slowly, a ray of light, passing through a hole made with a pin, in a thin sheet of lead, into a dark room, the ray will be seen to recede from the edge of the knife, in the direction *a d*, instead of its usual straight direction *a b*, ſee Fig. 29. This single experiment has been thought ſufficient to establish the doctrine, that light was reflected before it touched the surface of the reflecting body; that it approached that critical place, where the sphere of attraction ended, and where the sphere of repulsion began, and from that place was thrown back. As it has been proved, in the first lecture, that the elasticity of bodies was occasioned by the repulsive power of fire or light incorporated with them; and as all bodies in nature are subject more or less to the two contending powers of attraction and repulsion, there must be a ſpace or point where those two

powers will balance each other. Suppose, for instance, the line *a b*, Fig. 25, was the surface of a body; and the line *c d*, the boundary of attraction and repulsion; that is, the place where the sphere of attraction is said to end, and where the sphere of repulsion begins, as represented by the arrows in the figure. It is not, however, to be understood, that the sphere of attraction completely ends at *c d*, or that repulsion begins there; but that the attractive tendency towards *e*, and the repulsive tendency towards *g* (from the fire within the body), balance one another at *c d*. But as heat encreases the repulsive power of fire, either in a latent or an active state, and cold diminishes it, the line *c d*, must be very uncertain in its distance from, or in the body; for, in extreme cold, I should suppose the boundary would be within the body. But, in hot or cold, colours remain much the same, and light is reflected much alike. How is this reflection then to be brought about, by an imaginary space, where the sphere of attraction is said to end, and that of repulsion to begin? Reflection may be assisted by an emanation from the reflecting body of the light it has already imbibed; and, when in a state of heat, may emanate so powerfully as to turn the weaker rays back, before they touch the reflecting body. Chemical attraction is but the attraction of cohesion, applied to particular bodies, said to have an affinity, or choice, in th eir union with one another. Diamonds have an affinity to light; so have various phosphori: white bodies may also be said to have a chemical aversion to light, and to throw it all off: other bodies may only have a chemical rejection to a particular part of light, as green cloth rejects the green, and absorbs the other six parts of the light that fall upon it: other bodies may reflect two colours, so mixt, that they are distinct from any of the seven primitive colours. Therefore, from the shades and mixtures of different colours, arise that diversity of hue in silks, cottons,

linen, &c. that almost exceeds the power of numbers. It is true, dyes do but consist of three colours, red, blue, and yellow; for from these (by mixture) can all the rest be made.

When light impinges, or falls, upon a polished and flat surface, rather more than half of it is reflected, or thrown back in a direction similar to its approach; that is to say, if it falls perpendicularly on the polished surface, perpendicularly it is reflected. But if it falls obliquely on the looking-glass *a b*, Fig. 29, *with the same obliquity it will be reflected.* The incident ray *c d* is thrown back in the direction *d o*, making with the perpendicular, *d s*, the same angle that *c d* does with it. For it is a rule in catoptrics, *that the angle of incidence is always equal to the angle of reflection*; that is, the angle *c d s* is equal to the angle *o d s*, in all cases of obliquity. So a ray from the star *d*, falling on the looking-glass *a b*, Fig. 30, would be reflected to the eye at *e*: but as we see every thing along that line, in which the rays come to us last, the star *d* is seen at *s*; agreeably to the above law that the angle of incidence *e o n*, is equal to the angle of reflection *n o d*.

Why do I see my face in a looking-glass? If the face be strongly illuminated by the sun, or a candle, it may be said to emit light, particularly towards the mirror *a b*, Fig. 26; but (not to croud the figure with lines) we will take a ray from the forehead *c e*, which, agreeably to the angle of incidence, and reflection, will be sent to the eye at *o*: But the mind puts *c e o*, into one line, and the forehead is seen at *h*, as if the lines *c e o* had turned on a hinge at *e*.

Indeed it seems a wonderful faculty of the mind, to put the two oblique lines, *c e*, and *o e*, into one straight line *o h*; yet is it seen

every time we look at a mirror; for the ray has really travelled from *c* to *e*, and from *e* to *o*, and it is that journey that determines the distance of the object: and hence we see ourselves as far beyond the looking-glass as we stand from it. Though a ray, in this case, is only taken from one part of the face, it may be easily conceived, that rays from every other part of the face must produce a similar effect; and, therefore, that the whole face will be seen as far beyond the glass as the face is from it.

As the human eye is placed in the highest part of the body, the whole person may be seen, in a looking-glass of but half its length and breadth; as in the mirror *a b*, Fig. 31, the rays from the head, travel to the mirror in the line *A a*, perpendicularly to the mirror, and are returned to the eye in the same line, viz. *a A*: consequently, having travelled twice the length *A a*, a man must see his head at *B*; rays from his feet *C*, impinging on the bottom of the mirror at *b*, will be reflected to the eye, in the direction *b A*. But seeing his feet along the ray that approaches his eye last, he sees his feet at *d*, along the line *A b d*, and so of all the rest of his person.

These examples may serve to prove that the angle of incidence, and the angle of reflection, are always equal: and if properly understood, will easily explain the effects of diverging, and converging rays; of concave, convex, cylindrical, or any other kind of mirror.

If rays come diverging to a mirror, they will diverge, in their reflection, the same as if they had gone forward; thus the rays *a b*, and *b c*, would go on towards *f* and *g*, if not met by a mirror; but by it they are turned into the direction *m n*, Fig. 32.

The converging rays *a b* and *c d*, Fig. 33, would go on, and meet at *o*, if not prevented by a plane mirror, which so turns them as to make them unite at *n*.

Converging rays issuing from the object *a b*, Fig. 34, would be narrow enough to enter the pupil of the eye at *c*; but being met by the mirror *d e*, they reflect converging to the eye, *n*, which sees the object *a b* at *s*, behind the glass with the same obliquity as it was before the glass.

As a circle may be conceived to be made up of innumerable straight lines, so may a globe, or a slice of a globe, be conceived of innumerable small flat planes; these planes lying obliquely to one another, will reflect the rays of light diverging; and of course convex mirrors spread out the rays that fall upon them; thereby diminishing the appearance of the object, and painting it nearer to the mirror.

Fig. 35, *a b*, is a dart, to be seen in the convex mirror *c d:* but though rays issue from the dart in all directions, and to every part of the mirror, yet it is only those that fall upon it in the space between *o* and *n* that can be reflected to the eye; agreeably to the law, that the angle of incidence is always equal to the angle of reflection. This law sends the rays *o r* and *n r* more diverging than if the mirror had been out of the way; for in that case they would have united at *p*. Hence the angle *o r n*, being so much less than *a b p* (had the eye been at *p*), the image *s* will be less than the object, and nearer the mirror.

N.B. Large objects near a convex mirror, appear bent; because

one part of the object is nearer the mirror than another, so as to produce a sensible difference of angle.

A person looking at his face in a convex mirror, has it diminished, as Fig. 36. To keep the figure distinct, a ray may be taken from his forehead, and another from his chin. Now, though rays flow from his forehead so as to cover the whole mirror, it is only the ray that falls at *c* that can (agreeably to the law respecting the angle of incidence and reflection) be reflected to his eye. But his eye, transferring every image along that line, in which the ray comes to it last, sees his forehead along the line *o c n*. So the ray from his chin *a r* will, agreeably to the same law, be reflected to his eye at *o*, and of course he will see his chin along the line *o r s*. Now the angle of vision, *n o s*, being so diminished, the rest of his features will be seen diminished in like proportion.

Concave mirrors enlarge the appearance of objects, by increasing the visual angle, for the same reason that the convex diminishes objects by contracting the angle. Both concave and convex mirrors are generally a portion of a sphere; and the inner ſurface of a sphere brings parallel rays to a focus at one-fourth of its diameter, as may be seen in Fig. 37, where solar light would unite and burn at the focus *a*. Or, if a candle were placed in that focus, its light would be reflected parallel, as in the figure.

The magnifying power of the concave mirror may be illuſtrated by Fig. 38, where a face, A, is looking at itself. We shall here again, for the reason given, only take a ray from the forehead, and another from the chin. Rays issue from every part of his face, upon all parts of the mirror: but it is only *a c* that can paint his

forehead; that ray is reflected to his eye from *c*, and as he sees every thing along that line, in which the ray comes last to his eye, the mind puts the lines *a c* and *o c* together, and they make the line *o c d*, the real diſtance which has been travelled by the ray from his forehead; and where his forehead will be seen. Certainly rays issue from his forehead on all parts of the mirror; but thoſe rays that fall on the mirror at *g*, would be reflected to his chin uselessly, since he cannot see with his chin. In short, it is only that critical place *c* which (by the law of the angle of incidence and reflection) can be reflected to his eye.

The ray from his chin, that falls upon the mirror at *n*, will, by the same law, be reflected to his eye; and along the line *o n q* he will see his chin. The whole visage being, therefore, seen under the angle *d o q*, must be greatly magnified.

If the dart *a b*, Fig. 39, be held above the eye, and before a concave mirror, *c d*, it will be seen by an eye at *o*, magnified at *s t*. For the ray *b n* will be reflected to the eye in the direction *n o*: so *b n* being put to the end of *n o*, *b* will be seen at *s*. A ray, *a m*, from the other end of the dart, will approach the eye in the direction *m o*; and *a m*, and *m o*, put together, will make the line *o m t*, where that end of the dart will be seen, consequently the dart *s t* will be the image of the object *a b* greatly magnified.

These effects only take place when the object is between the mirror and its focus. But when the object is farther distant than the focus, the rays croſs, and the object (if ſeen) is seen before the mirror, and inverted. Thus, if the concave mirror be large, as *a b*, Fig. 40, and a hand be held up before it, and without its focus, its image inverted will be ſeen hanging in the air at *m*.

For rays go diverging from a point, as *c* and *d*; and by the mirror are brought again to a point at *a* and *s*, where they cross, and in that state proceed to the eye.

Hence, if a man, holding out a ſword, approach a large concave mirror, an opponent ſeems to meet him with a drawn ſword: and a perſon holding out his hand in approaching the mirror (at a diſtance farther than the focus), will have another meeting his, as if inclined to ſhake hands with him. If the hand turn a little on one ſide, the image will move the contrary way, &c. Hence alſo thoſe deceptions (where a mirror is concealed), of birds and angels flying: the hand attempts to lay hold of them, and finds them nothing. A noſegay is ſeen, and when the hand attempts to take hold of it, a death's head ſnaps at it, &c. &c. If a large concave mirror be ſo placed before a bright fire, that its image may be ſeen on a table; thoſe unacquainted with the cauſe, expreſs the utmoſt aſtoniſhment on ſeeing a fire burning on a table!

If two large concave mirrors be placed oppoſite each other, as Fig. 41, at any diſtance, and red-hot charcoal be held in the focus at *a*; a match, or brown paper, or any thing very combuſtible, held in the other focus at *b*, will be preſently ignited: ſhewing that common culinary fire is liable to the ſame flexibility as light.

Hold a decanter, half full of water, a little farther than the focus, from a concave mirror; and the decanter will be ſeen inverted: if then the water be poured into a baſin, the decanter will appear in its natural ſtate, and to be filling inſtead of being emptied.

These deceptions may be multiplied into innumerable varieties.

Priestcraft, availing itself of the properties of the concave mirror, rekindled the vestal fire: and Archimedes is said to have burnt the Roman fleet with one.

Anamorphoses are produced from the pictures of objects as seen in concave cylindrical mirrors; which distort objects by bending their images into the same curvature as the mirror: thus, if a face look at itself in the cylindrical mirror *a b*, Fig. 42, it will see itself elongated like the figure A. But if this figure were drawn, and a convex cylindric mirror placed before it, it would be brought back to its true figure B.

Having thus gone through what may be called the principles of optics, it is now time to apply these principles to the explanation of optical instruments, vision, and the rainbow.

The rainbow is certainly the most beautiful meteor in nature. As it never makes its appearance but when a spectator is situated between the sun and a shower of rain, it follows that the sun and drops of rain cause the phænomenon. If an hollow glass globe be filled with water, and suspended so high in the sun above the eye, that the spectator, with his back to the sun, can see the globe red; if it be lowered slowly, he will see it orange, then yellow, then green, then blue, then indigo, and then violet; so that the same drop, at different heights, shall address to the eye the seven primitive colours in succession. *Example.* Let A, Fig. 42, be a drop of rain, and *S d* a ray from the sun falling on the upper part of the drop at *d*. It will suffer a refraction, and instead of going forward to *c*, it will be bent to *n*; there it will be in part reflected (for some will pass through the drop) to *g*; where, by the obliquity with which it falls on the side of the drop, that part

becomes a kind of prism, and separates the ray into its primitive colours. Hence we find, that after a ray has suffered two refractions and one reflection, as in the figure, the least refrangible part of it (the red) will make an angle with the incident solar ray of 42° 2′, as *S f g*; and the violet, or greatest refrangible ray, will make with the solar ray an angle of 40° 17′, as *S c g*. This holds good at whatever height the sun may chance to be in a shower of rain: if high, the rainbow must be low; if the sun be low, the rainbow is high: and if a shower happen in a vale when a spectator is on a mountain, he often sees the bow completed to a circle below him. So in the spray of the sea, or a cascade, a circular rainbow is often seen; and it is but the interposition of the earth that prevents a circular spectrum being seen at all times, the eye being the vertex of a cone, whose base (the bow) is in part cut off by the earth. The drop, therefore, in falling the distance *b g*, will address to the eye, *g*, the seven colours in succession; but that succession is so quick, and so many other drops fall through the same circuit in the same time, that the mind loses the idea of succession, as it would in a whirling firebrand, and the bow seems permanent so long as the shower continues in the proper direction from the eye. Cones, therefore, passing from the eye through a shower, and making the above angles with solar light, will always produce a rainbow: and hence, if several people are standing together, looking at the bow, they every one see a different bow; for they are each the vertex of a different cone. The bow, therefore, moves as the spectator moves; for the eye E, Fig 43, by the smallest motion ceases to be the centre of the spectrum *a b*; and other drops, in another circle, producing the same effect, make him believe it the same rainbow. Suppose the outermost circle, *c c*, the plane, through which the drops falling, produce the red colour to the eye E; and that the lowest circle, *d d*, produce the violet; so that the intermediate

circles may be conceived as interior cones cut through the shower, one within another; then would drops passing through these surfaces produce the seven colours, though some might be within a few inches of the eye, and others some miles from it; for wherever the above angles took place, either in near, or in distant drops, the colour would still be the same.

These are the circumstances that produce the interior or principal bow: but a faint exterior bow generally accompanies the principal bow. This is produced by drops of rain above the drop A, as B, where the ray to be sent to the eye enters the drop near the bottom, and suffers two refractions and two reflections; by which the colours become reversed, i. e. the violet is lowest in the exterior bow, and the red is lowest in the interior bow, and so of the rest. The ray T suffers a refraction at *r*; part of it is reflected from *s* to *t*, and from *t* to *u*: we say part of it, because a portion of the ray passes through the drop at *s* towards *w*, and another portion at *t* towards *x*: by these losses the exterior bow becomes faint and ill defined, in comparison of the interior bow. Let us now carry these principles to the bow itself. The spectator A, Fig. 44, being in the centre of the two bows in the figure (the planes of which must be conceived as perpendicular to his view), the drops *a* and *b* produce part of the interior bow by two refractions and one reflection, as above; and the exterior, by the drops, *c d*, producing two refractions and two reflections: the sun's rays being represented by the lines *s s s s*. The angle formed by the red ray in the exterior bow and the solar rays is of 51°; and with that of the violet ray, of 54°.

On Vision.

As the eye is the grand inlet to most of our pleasures, no wonder that a more than ordinary attention has been paid to the structure of that divine organ. It is placed in the highest part of the body to command distant prospects; moves easily in a cavity of bone in every direction; is wiped and protected by lids that keep perpetually opening and shutting; and smaller accidents are prevented by a palisado of lashes. Its interior structure it not less curious. Light only has natural access to the sensitive part of this organ; but by any other impression the optic nerve produces in the mind the idea of light: such as a blow upon the eye; thrusting the fingers against it; or a sudden shock or surprize. This film is the medium between corporeal impression and sensation; it is the handmaid that conveys to the mind the images made upon it by light from outward objects. It is not sight; but it is a screen on which a picture is painted, and held to the mind's eye. This impression is made by the optical instrument called the eye: the structure of which is as follows:

1st. The sclerotica, a strong, unelastic coat, that holds tenaciously the optical part of the eye within its globular concavity; on the outside of which are fastened the muscles that direct the eye towards objects, with their opposite ends fastened to the cavity of bone in which the eye moves; so that, by the contraction and dilatation of these muscles, the eye is moved in all directions with the utmoſt quickness. One part of the sclerotica is transparent, and bulges a little out of the globular figure; as *a c*, Fig. 62. In the human subject it is round, and forms the front part of the eye; in many other animals it is oval: this prominence is called

the cornea; from its being so like horn, and so well calculated to transmit light.

2d. Within this lies a soft pulpy lining, called the choroid membrane, circle 2, Fig. 62. black in the human subject, white in cats and owls, and green in animals that live upon grass and vegetables: this seems a lining or bed for the optic nerve to lie upon; and is of too weak a texture to acquire motion by muscular action, except at its extremities, which form a circular ring of muscular fibres, called the iris, as *s s*, Fig. 62; and these fibres surround a round hole for light to pass through, called the pupil, as *o*. The iris, *s s*, is of different colours in different people, as blue, black, grey, &c. and supposed to be so irritable, as to be affected, and to contract, by strong light, and relax by darkness, or weak light. This is very observable in a young child; when just awake, the pupil will be almost as large as the cornea, *a c*; but on being brought into the sun, the pupil will contract to the size of a pin's head. A wise provision! for, as the child has not yet acquired strength to move the head or eyes, was intense light to strike the retina when the pupil was so open, it might injure that delicate membrane, so as to render it insensible, and induce the disease called *gutta serena*. By holding a candle close to a cat's eye, the same contraction is observable.

3d. On the choroid membrane lies the retina, or optic nerve, the sensitive part of the eye, circle 3, Fig. 62. This nerve, like all others, is but a continuation of the medullary matter of the brain; it enters the eye, on one side of the axis, or line of vision, at *u*; and, like a fine net, spreads over the whole interior surface of the eye. It is of an ash-coloured white; so that by the black bed, or back ground, on which it lies, colours and shapes must be very distinct upon it; for it is on this fine membrane that ob-

jects are painted by the crystaline humour, as a window would be by a common spectacle-glass, on a sheet of paper; from which picture our mind conceives the shape, the colour, and distance of all objects we look at. This film is represented in section by line 3, Fig. 62. but its entrance, *u*, is insensible; for if three black spots of about half an inch diameter, be placed in an horizontal line, a foot from each other, as *a b c*, Fig. 63, and a person stand four feet from them, if he cover his left eye, A, and look steadily with the other at the left hand spot, *a*, the middle spot, *b*, will disappear, though he will see plainly the two outside spots, *a* and *c*. But on looking with both eyes at the three spots, it will be evident, from the figure, that the spot *b*, which falls on the entrance of the optic nerve in the eye, B, will not fall on the optic nerve in the eye, A; and therefore, in looking at the three spots with both eyes, we see them perfectly. A blood-vessel enters the eye with the optic nerve, and seems to indicate a muscular energy in it; particularly at its extremities in the *ligamentum ciliare*, which unites it with the crystaline humour, *d*, at *b b*, Fig. 62. This radiant processus surrounds the crystaline humour, *d*; and perhaps, by its muscular force, may elevate or depress it, so as to adapt the humour to near or distant objects. For the vitreous humour, B, which fills up the general body of the eye, is a jelly-like transparent substance, very flexile, and capable of suffering the crystaline humour to be depressed into, or elevated above it; so that the eye may be a globe, or a prolate spheroid (an egg-like figure), as is most convenient for seeing near or distant objects. This we conceive to be the use of the ciliary ligament; for certainly the eye assumes a different figure, whenever we strain it to see distant, minute, or indistinct objects.

5th. The crystaline humour, *d*, is a lens of great magnifying

power, very dense, and made up of thin lamillæ, so that if some of the coats become diseased, and opaque, as in the cataract, they may be separated or depressed, without much injury to the rest; though it is not uncommon to extract the whole lens, or press it into the vitreous humour. This lens has its focus on the retina, and, like other lenses, paints any luminous or illumined object at that focus. The middle part of it may be seen through the pupil of the eye; its outsides are wisely covered by the iris, to prevent prismatic colours from confusing vision; for the edges of all deep magnifying lenses, are in reality prisms. It is made still more achromatic by,

6th. The aqueous humour, *o s s*, which, with a limpid water (incapable of freezing), fills up the space between the cornea, *a c*, and the crystaline, *d*; and in the middle of which is the iris, *s s*. These are the coats and the humours of the eye, which is, as we have said, an optical instrument, admirably calculated to paint objects on the retina or optic nerve: for instance, if I were looking at my pen, its picture on my retina would be the bent inverted figure, seen in the eye A, Fig. 64, agreeable to the effect of the double convex lens, as before explained. But, if inverted, why do I see it upright?—All our senses may be said to be modifications of the sense of feeling. When I lay a finger upon my arm, the nerves passing that place, convey to my mind the sense of feeling.—If I press that finger against my eye, the retina conveys to my mind a sense of light: impressions of a like nature made on my tongue, or the recesses of my nose, would produce the sensations of taste and smelling: and could I touch the nerves of the ear with my finger, no doubt, the sensation would be like a clap of thunder, or some prodigious noise. All which shews our sensations to be produced by mechanical impressions: and light, as a

material and moving substance, can make a mechanical impulse upon the sensitive part of the eye, and produce upon it something like feeling; (for the boy couched by Cheselden thought, when he first saw the light, that every object touched his eyes). But the retina differs from the nerves of feeling, in that it has no perception *where* the impressions of light are made upon it. It was neceſſary for our preservation, that we ſhould promptly distinguish where any impression was made on the outside of the body; but, for a sense inclosed within the skull, that kind of perception was unnecessary; and we never find that nature does any thing in vain. Could I perceive, that when I hold a candle below my eye, it was painted on the upper part of the retina; or, that when I held the candle above my eye, it was painted on the lower part of the retina, the objects I look at would certainly appear, as the picture, inverted. But I have no such perception: I only know, by dissection, in cutting away the sclerotica and choroid membrane from the back part of the eye, and holding a candle before it, that the candle is inverted, and painted as above. But the dead eye has all the parts of the living eye, and therefore the effects must be the same. The end of the pen *c*, Fig. 64, being painted at *a*, and the other end, *d*, at *e*, shews the pen inverted; but I do not feel it inverted; the retina does not inform me that the top is painted at bottom, and *vice verſâ:* but as it is a property of the mind, to transfer every object along that line in which the rays approach the eye last, the rays from *c* approach the retina at *a*; and the rays from *d* touch the retina at *e*. The mind, therefore, transferring the end *c* along the line *a g c*, to the place where it is; and the end *d* along the line *e g d*, to the place where it is; of course the object must appear to the mind upright, notwithstanding its inversion on the retina. Distinct vision requires the rays issuing from any object to come tolerably parallel; for, the more they come to the

eye converging, the more indistinctly is the outside of the object seen.

Objects appear large or little according to the angle in which the rays from them approach the eye: thus, the picture of my pen on the retina of the eye B, Fig. 64, is but half the size it is in the eye A; because it is twice the distance from it: for the angle of vision, *c g d*, is double that of *c f d*. Yet I can judge of the size of the pen at B as justly as at A; but this is from experience; for we learn to see by time and observation. A child grasps at the moon, as it would at a candle within its reach; and a person couched, and brought to sight of a sudden, believes, as before observed, that every thing touches his eyes. Had the study of optics, or nature, been a part of the education of our forefathers, ghosts and apparitions would not have affected their imaginations. Indistinct vision in the night, mineral and animal matters mixed with light, spontaneous ignition by inflammable exhalations, and electricity, &c. would have accounted for the cause of all their fears. For the impressions made on the retina, like pain in feeling, will last many seconds after the impression has been made; so that ignorance would conceive something seen, even when the eyes were shut. If the eye meet a glowing sun, and instantly close, a white image of him will be strong on the retina; continuing shut, the image will turn violet, then blue, then green, and if the impression were very strong may go in gradation through all the prismatic colours. Is it not probable that the retina has a power of absorbing light, and that the weakest is absorbed first, the blue next, and the red (as the strongest) last of all? Heat, however, expels latent fire, or light: Canton's phosphorus, hermetically sealed in a glass, and held in the sun to imbibe light, is quite dark in a dark room: but if held near a hot iron, the light will appear so vivid, that the hour may be seen

upon a watch in the dark; the whole light will be expelled by the heat; and it will become quite dark till again impregnated with light by being exposed to the sun. Common phosphorus, heated by being rubbed between pieces of brown paper, instantly ignites. Fuel will not part with its latent fire, until it is heated, &c. &c. and iron will not burn even in vital air, till heated.

The general defects of the eye are, too long a sight, or too short, and squinting. As the crystaline humour partakes of the general decay of old age, and grows flatter; so its focal length increases: hence age is obliged to hold objects very distant from the eye, to make their image come to a convergence on the retina; otherwise, if held at about six or eight inches (the usual distance for distinct vision), the image would be imperfect on the retina, as the focus of the crystaline is farther than the retina: this will appear in Fig. 45, in the eye A; where the flatness of the crystaline, *c*, would have its focus at *r*, beyond the retina, *e*. This defect is remedied by the spectacle-glass *d d*: which may be considered as a part of the crystaline; making up, by its bulgency, that want in the crystaline; so that both together they make one lens of the same focal length, as the crystaline was in youth; and the image becomes distinctly painted on the retina. This spectacle must increase in bulgency as the crystaline grows flatter; and hence the necessity of its frequent change.

The short-sighted defect arises from the crystaline and cornea being too convex: for by bringing the rays to a focus in the vitreous humour at *r*, before it reaches the retina, as in the eye B, Fig. 46, the image will be as indistinct as in the old eye. Hence, without a spectacle, objects are held close to the eye, that the rays may converge farther back: but a concave spectacle, *c c*, by

its attraction towards its edges, spreads the rays outward, and thereby counteracts the too great contraction of the crystaline; sending forward the image *r* to the retina *g*; agreeably to a former doctrine relative to the effects of concave lenses.

Squinting is a disease of the muscles which move the eye in its socket. If one becomes rigid, and will not give way to the action of the other muscles, this will hold the eye in one position; as is the case with those eyes that always seem looking towards the nose. Other eyes squint partially, as when the muscle that directs the eye one way, is not a balance for its antagonist muscle.

A speck, or cataract, is sometimes on the crystaline, and sometimes on the cornea; commonly occasioned by inflammations in the eyes. If it be before the pupil, its opacity, stopping the rays of light, occasions blindness. The edge of the cornea being separated from the white of the eye, needles can be introduced to depress the speck, scratch it off, press the whole crystaline into the vitreous humour, or totally to extract it. Nature will supply another crystaline, or fill up the cornea with a matter that will supply its place, with the assistance of a deep or bulging spectacle.

Optical Instruments.

The Galilean telescope is one of the most ancient instruments of its kind; called so from the justly-celebrated philosopher Galileo, of Tuscany. This telescope, with which he discovered Jupiter's satellites, &c. consists only of two glasses, a convex and a con-

cave lens; and is, at large, what our opera-glasses are in miniature. Suppose *a b*, Fig. 47, a dart at a distance, which I want to magnify: if the object-lens *c d* (in the end of the tube) be held parallel to the dart, it will bring the rays from it to a focus at *r n* (according to former explanations), and a paper held there would exhibit the picture *r n*, if the object *a b* be sufficiently illuminated. But if I interpose between the picture and the lens the concave *e f*, whose attractive power is towards its outside; it will then turn the ray *b c o r* into the direction *b c o q*; and the ray *a d o n* into the direction *a d o m*; and so of the rays *a c n* and *b d r*. The lens, *e f*, is made in the figure much too large, that it might not be perplexed with crouded lines; but it must be supposed, when held close to the eye, that the space, *o o*, is not bigger than the pupil of the eye; so that the diverging rays *o q* and *o m* are continued to the retina. But this cannot be true, for only a few of the rays enter the eye, and therefore the object is seen very imperfectly; and the instrument is seldom used but for short distances, as in opera-glasses, &c. Now as that sense transfers every object along that line in which the rays last approach it, the lower end of the dart is seen along the line *q o s*; and the upper end along the line *m o t*; the image magnified and brought nearer. The distance between the two lenses must be the difference between their focal lengths; i. e. if the focal length of the lens *c d* be twelve inches, and that of *e f* four inches, then the difference is eight inches, the length of the tube; and the magnifying power will be three times; (the number of times the focal length of *e f*, is contained in the focal length of *c d*).

This telescope has the most light of any; but the smallness of the field of view is its greatest defect.

The Night Glass

Is a refracting telescope for discovering distant ships in the night: it commonly consists but of two lenses; an object-glass *a b*, and an eye-glass *c d*, Fig. 60. This instrument sometimes has a double eye-glass to prevent prismatic colours; but this is a defect, for every lens reflects and loses a quantity of light from its two surfaces, and in the night there is no light to lose: the lenses, therefore, are large, to concentrate as much light as possible; and every object is inverted, as in the Fig. 60. The topmast *e f* (being all we suppose that can be seen above the water) having its light refracted by the object-lens *a b*, and brought to a focus at *g*, has its image there inverted within the tube of the instrument: the eye-glass *c d* being placed in coincidence with the focus of the object-glass *a b*, sends the rays into the eye E, in the direction *c o* and *d n*, forming on the retina the image *o n*. Every part of an image being transferred along that line in which the rays approach the retina last, the bottom of the object, *f*, is seen along the line *o m*; and the top along the line *n s*, greatly magnified. As this telescope inverts all objects, they seem to move the contrary way to the motion of the instrument; and its magnifying power is as the focal distance of the object-glass to the focal distance of the eye-glass; i. e. if the focal distance of the object-glass be twelve times as much as that of the eye-glass, then will the object seen be twelve times as long, and twelve times as broad, as when seen by the naked eye. This telescope was made formerly of thirty or forty feet long; nay, its object-glass was sometimes fixed upon the top of an high tower, so as to be adjusted by a wire communicating with the eye-glass at bottom: for lenses of a very long

focus unite the rays, and prevent the prismatic colours that generally surround the field of view, and, of course, lessen the distinctness of the object. For seeing terrestrial objects upright, we use

The Refracting Telescope.

This instrument differs not much in principle from the last; but by having two convex lenses, *c* and *d*, Fig. 50, placed on the opposite sides of the sphere of their convexity, the image is rendered upright: and two eye-glasses, *e* and *f*, magnify the image, *s t*, to the size S T. The object, therefore, to be magnified, A B, being by the object-lens *a* brought to a convergence, and its image painted within the tube at *b*, the rays passing through *c* and *d* give the second image *s t*: this image is so magnified by the eye-glasses *e* and *f*, that it appears to the eye, *z*, under the angle T *z* S.

But to render this instrument achromatic (that is, its field of view *colourless)*, we must first enquire what causes the circular prismatic rings of colour in ordinary spy-glasses. Let parallel rays pass near the edge of the lens *w x*, as *v* and *n*, Fig. 62, and they will be found *not* to assemble in a point: the most refrangible part (the violet) will assemble at *o*; and the least refrangible part (the red) at *p*; and so of the intermediate colours. Hence the focus of the lens, *w x*, will be a circle, whose diameter, *a b*, is perhaps half an inch, or more; of course such an object-glass as this (its edges having this prismatic effect) must tinge the field of view with red, blue, green, &c. Now the suggestions of Newton, the endeavours of Euler, and the finishing of Dollond, have united these scattered

rays into one mathematical point. These were the means, viz. The dispersive power of glass is very different. *Crown-glass* is composed of sand, fluxed by means of the ashes of sea-weeds, barilla, or kelp; and has the least dispersive power of any glass: *plate-glass* is made of sand, melted by means of fixed alkali; and has a greater refractive or dispersive power: and *flint-glass* is composed of flint-sand, melted by means of fixed alkali and minium, and has a greater refractive or dispersive power than either of the other. If, then, the lens *w x*, Fig. 51, be of crown-glass, and the concave lens *c d*, of white flint-glass (the concave of the same radius as the convex), they will fit into one another, and become, as it were, one lens. They are placed at a distance from each other in the figure, for easier explanation. Now as the dispersive power of the concave lens is towards its outside, while that of the convex lens is towards its centre, they will counteract the effects of each other, and the least refrangible ray will be made to meet the most refrangible ray at *z* and *y*. Thus the violet ray *w o*, being bent the contrary way by the lens *c d*, will meet the red ray, and all the rest, at *z*; and the least refrangible ray, viz. the red, *w p*, being bent at *i*, will pass on to *z*, crossing the general focus there. The same effect will be produced on the rays *x o* and *x p* by the concave lens *c d*, and they will assemble at *y*. Now here are two colourless points produced, viz. *z* and *y*. Cannot they be united? Yes: by the convex lens *g h*: which will join the two focuses in the mathematical point *k*. So that one combined lens is formed by two convex lenses of crown-glass, and a concave lens of flint-glass between them.

This achromatic effect may be produced by an union of one convex and one concave lens; but not so well as by the above three: and the proportional densities of the glasses to each other, require much professional practice and attention; for the greater difference

there is between the dispersive powers of the convex and concave lenses, a larger aperture can be admitted, and of course the object will be more enlightened. To produce this difference, lenses have been made of two meniscus glasses joined together, and filled with a pellucid liquor, the refractive power of which being much less than glass, would produce this difference; but it is difficult to keep any fluid from growing turbid for any length of time.

This compound achromatic object-glass giving so perfect an image of the object, can, in a tube of a few feet, admit of as great a magnifying power in the eye-glass as were in tubes of eighty or 100 feet long.

The most advantageous eye-glass is the one invented by Divini, and called Ramsden's eye-glass, being two plano-convex lenses, with their *convex sides inwards*, and placed so near as to be within each other's focus: the field of view is the most extensive, and the image least injured by the prismatic effect of the edges of the lenses.

In double convex lenses, the most perfect is that whose radius of curvature of the first surface, is to that of the second, as one to six: Its aberration being the least possible, viz. $\frac{15}{14}$ of its thickness: but if this glass is turned with its other side to the rays, the aberration will be $\frac{145}{42}$, and therefore would be much worse. The same ratio holds good in concave lenses.

N.B. The French plate-glass, and English crown-glass, reflect fewer rays, and admit more to pass through, than any other kind of glass.

Common object-glasses, will not bear an aperture and power, larger than the following:

Focal Distance of Object-glass.	Aperture of Object-glass. Diameter.	Focal Distance of Eye-glass.	Magnetical power.
Feet.	Inches.	Inches.	
1	0,545	0,605	20
2	0,76	0,84	27,6
3	0,94	0,04	33,5
4	1,08	1,18	39,5
5	1,21	1,33	44

The Reflecting Telescope.

This instrument performs, by reflecting the rays issuing from any object, what the last did by refracting them. Let *a b*, Fig. 65, be a distant object to be viewed: parallel rays issuing from it, as *a c* and *b d*, will be reflected by the metallic concave mirror *c d* to *s t*, and there brought to a focus, with the image a little further and inverted; agreeably to the effect of a concave mirror on light, as formerly deſcribed. The hole in the mirror *c d* does not distort or hurt the image *s t*, it only loses a little light; nor do the rays stop at the image *s t*; they go on, and cross, a little before they reach the small concave mirror *e n:* from this mirror the rays are reflected nearly parallel through the hole *o*, in the large mirror; there they are met by the plano-convex lens *h i*, which brings them to a convergence at *m*, and paints the image in the small tube of the telescope close to the eye. Having by this lens, and the two mirrors, brought the image of the object so near, it only remains to

magnify this image by the eye-glaſs $k\,r$; by which it will appear as large as $z\,y$, agreeably to former documents.

To produce this effect, it is necessary that the large mirror be ground so as to have its focus a little short of the small mirror, as at q; and that the small mirror should be of such a concavity as to send the rays a little converging through the hole o; that the lens $h\,i$ should be of such convexity as to bring those converging rays to an image at m; and that the eye-glass $k\,r$ should be of such a focal length, and so placed in the tube, that its focus may just enter the eye through the small hole in the end of the tube.

To adapt the instrument to near or remote objects, or rather to rays that issue from objects converging, diverging, or parallel, a screw at the end of a long wire, turns on the outside of the tube, to bring the small mirror nearer to, or farther from, the large mirror; and so as to adjust their focuses according to the nearneſs or remoteneſs of the objects. The sun-glass at the end of the small tube, should be unscrewed when any other object, except the sun, is looked at.

To estimate the magnifying power of the reflecting telescope, multiply the focal distance of the large mirror by the distance of the small mirror from the image m; then multiply the focal distance of the small mirror by the focal distance of the eye-glass $k\,r$; then divide these two products by one another, and the quotient is the magnifying power.

Of Microscopes.

These instruments assist the eyes in examining the minute parts of creation; and bring into view wonders of a different, though not of a less curious and extraordinary nature, than thoſe perceived by telescopes. They swell into magnitude atomical existence, thereby shewing the animal œconomy to be as perfect in the mite as in the elephant; and almost oblige the mind to conceive an idea of organized nothing.

The Single Microscope

Consists but of one small lens, as *a b*, Fig. 66. Now the angle under which the eye would see the small cross (without the lens), would be the space between the lines, which go from the top and bottom of it to the eye. But if the lens be interposed between the eye and the object, those lines would not meet at the eye; they would fall above and below it. But, by laws formerly explained, the rays *c a* and *d b* would enter the eye; and as the mind transfers every image along that line in which the rays approach it last, the top of the cross will be seen at *m*, along the line *o a m*; and the bottom at *n* along the line *o b n*. The angle of vision being thus increased from *e o d* to *m o n*. The lens *a b* may, therefore, be considered as a spectacle-glass, and as having its magnifying power, from thus increasing the angle of vision.

It is also fitted up in a handle, with moveable tongs or forceps to hold plants, insects, &c. and thence called a field, or botanic microscope.

The Double, or Compound Microscope.

This instrument, like the telescope, presents the eye with the image, and not with the object itself, as in the single microscope, Fig. 67. The lens *d e*, is placed a little farther from the object *a c*, than its focal length; so that the pencils proceeding from each end of the object would unite at *o* and *n*, if not met by the lens *r s*. This image would be too large for the eye, or the eye-lens *t u*, to take in. For rays issuing from objects are very different from thoſe issuing from an image: an object may be seen on all sides, if illumined by either direct or reflected light; but an image can only be seen in the direction of the axis of the lens that produces it; therefore the image *o n*, is brought within the influence of the eye-glass *t u*, by the lens *r s*. If now the eye-glass *t u* be so placed, that the image *o n* be in its focus on one side, and the eye in its focus on the other, the top of the image will be seen along the line *z t m*, and the bottom along the line *z u v*, consequently magnified under the angle *m z v*.

Solar Microscope.

This entertaining instrument consists of one plane mirror, and two lenses; the mirror *s o*, Fig. 68, is to be without the window shutter *d u*; the lens *a b* in the shutter; and the lens *n* within the dark room. These three parts are united to, and in, a brass tube; and the mirror can be so turned by adjusting screws, that however obliquely the incident rays *A* fall upon it, they (by the laws of the angle of incidence and reflection) can be reflected horizontally into the dark room through the illuminator *a b*: this lens collects

those rays into a focus near the object *c g*; where, passing on through the object, they are met by the magnifier *n*; here the rays cross, and diverge to the white screen, where the image, or shadow, of the object, *q r*, will appear. The magnifying power of this instrument depends on the distance of the white screen; and, in general bears a proportion to the distance the object *c g* is from the magnifier *n*; that is, if the screen be ten times that distance from the lens *n*, the image will be ten times as long, and ten times as broad, as the object. About ten or twelve feet is the best distance; for, if further, the image will be obscure, and ill defined, though larger: the lens *n* is brought nearer to, or farther from, the object, by an adjusting screw, so as to exhibit the image clear and sharp upon the screen. This part of the instrument is calculated only to exhibit transparent objects, or rather such as light can pass through in part; but for opaque objects we use the

Opaque Microscope.

Ores, flowers, insects, shells, &c. are seen to great advantage by this instrument. The mirror *a*, Fig. 51, and the lens *c*, are the same as those of the solar microscope; but the converging rays from *c* are met by a diagonal mirror *e n*, which throws up the rays much condensed upon the opaque object *s r*; from the object they are reflected to the magnifier *o*, from which they proceed diverging to the screen *p q*, where the object will be painted, and greatly magnified.

The objects are generally stuck by a wafer, or glue, to a thin

slider of wood, and not placed in the focus of the lens *c*, lest they might be burnt.

The Magic Lantern.

The office of the sun in the solar microscope is performed in this instrument by a candle, or lamp; rays from which pass through the lens *a*, Fig. 52, besides others reflected by the concave mirror *c*. These rays are interrupted by the inverted cross, which, if coloured, must suffer them to pass on to the magnifying lens *e*; here they suffer such a refraction, as to go diverging to the screen, where the cross will be seen duly magnified. The lens *e* must be brought nearer to, or farther from, the object, till its focus exhibits the image clear and well defined on the screen. Ludicrous figures, well painted in transparent colours, have a laughable effect in a dark room; and serious subjects, such as the motions of the heavenly bodies, can be well represented by this instrument.

The Camera Obscura

is sometimes made for viewing prints or pictures, and magnifying them; and sometimes for taking landscapes, &c. When the glasses are fixed in a box, or on a stand, their intent is to magnify pictures, as Fig. 53, where *a b* is a plane mirror, placed at an angle of forty-five degrees with the horizon, and *c d* a large lens, placed perpendicularly before it. If then a picture, *e f*, be laid inverted under the mirror *a b*, and be strongly enlightened by the sun, or by

candles, rays issuing from it in all directions, those that impinge on the mirror will be reflected to the lens *c d*; which will bring them to a focus on the retina of the eye E. Now the eye transferring every part of an object along that line in which the rays from it came to the eye last, the top of the object will be seen in its right position along the line E *c a i*, and the bottom along the line E *d k*, greatly magnified.

When this instrument is used for taking views, the mirror is placed above a dark box, but moveable up and down, so as to adapt it to the height of the object to be copied. Fig. 54 represents its rationale, without the dark box. *a b* is a plane mirror with adjusting screws, to make it form a convenient angle with the tower *c d*; which, if strongly illumined by the sun, rays from it will fall on the mirror, and be from thence reflected perpendicularly through a hole in the box in which the lens *u n* is fixed: this lens will bring the rays to a focus on the screen, or paper, *e s*, on which the tower will be painted inverted. The effect of this instrument depends upon the angles of incidence and refraction, viz. the ray *d b* will be reflected in the line *b e*; and the ray *d a* in the direction *a i*. So likewise the ray *c b* will be reflected in the line *b n q*; and the ray *c a* in the line *a h*: but these lines being met by the lens *u n*, it will refract the pencil *b d a* so as to make it unite at *e*; and the pencil *c b a* so as to unite at *s* (the top and bottom of the tower); and pencils from every other part of the tower suffering the same effect, the tower will have its image inverted on the paper, but so vividly in a dark box, as to be capable of being drawn to a peculiar exactness. The lens must be so moveable up and down as to be capable of adjustment to near or distant objects: and the dark box should be big enough to hold a man; or if small, must have a hole to see through, and another, through which the arm can be put.

MISCELLANEOUS EXPERIMENTS, DECEPTIONS, &c.

A FEW years ago the Brethren of the Trinity-house applied to me to give a design for a light on St. Mary's Isle, in the islands of Scilly. That important station required a light of great intensity; of large volume; to be seen on all sides; and to be distinguished from all other lights. Considering that much light is reflected from the two surfaces of lenses, and, of course, lost to distant observation; and that mirrors added much to the natural light of a lamp, in one direction, I united seven parabolic concave mirrors in one perpendicular frame, as Fig. 55, with an Argand's lamp in the focus of each mirror. The mirrors were twenty-two inches in diameter, of copper, plated with polished silver surfaces, so that the volume of light is five feet and a half in diameter, and appears like one united blaze of light at a distance: the reservoirs of oil are fixed behind each mirror. To distinguish this light at sea from all others, and to enlighten all sides of the horizon in succession, I contrived a machine to turn the whole frame of lamps round on the upright shaft, *a*, in two minutes; the light thus appearing and disappearing at the end of every second minute, gives the approaching seaman a perfect assurance *what* light it is. As it is a property of the parabolic curve to reflect the light that falls upon it, from *c* its focus, in parallel lines, as *d d*, &c. the whole seven mirrors send out a cylinder of light, that as it passes the spectator appears for a moment of unusual splendor; so that by observing that, and the next return of its brilliancy by his watch, he easily perceives it to be the Scilly light.

This was the first on this plan of several that have been copied from it.

2d. Large lenses, and concave mirrors, painting the image of objects in their focus, if they are well enlightened, give scope for variety of deception: to stand, with the eye in the axis of a large convex lens, the image of the object will be seen in that line, as if suspended between the lens and the eye. A large metallic, or glass, concave mirror, placed on the back part of a dark box, produces appearances that are truly surprising. Let *a*, Fig. 56, be the mirror; *d* the actor, concealed by the cross partition *c*; *e* a strong light, also concealed by the partition *i*. If *d* holds a book, or any other object, the light reflected from it will pass between the screens, or partition, *c* and *i*, to the mirror, and be from thence reflected to *z*, where the image of the book will appear so tangible, that the spectator, looking through the opening *x*, will suppose he could take hold of it. The confederate *d* may actuate various moving figures, as flying birds, angels, demons, &c. the effects of which at *z* would be very surprising.

3d. If the head of a pin (or any small object), *a*, Fig. 57, be held near the eye, and before a small hole in the black pasteboard *c* (the light, or the white paper *d*, being a back-ground), the pin will appear on the opposite side of the board *c*, inverted, and magnified as *x*. The object *a* being within the focus of the crystaline humour *s*, will cause the image of it to be painted on the retina at *r* without inversion; i. e. it will be painted on the optic nerve with the same end up as it is held in the hand, and, of course, appear inverted. But in reality it is the shadow of the pin that is painted on the retina; for the light from the lower part of the paper *d* will be

stopped by the head of the pin; and that from the upper part will be stopt by the leg of the pin, in passing through so small a hole as *a*; and those rays cannot cross within the eye as usual, but will go parallel and upright to the retina; so that to the mind, the object must appear inverted. A pin's head cannot be seen when held so near to the eye as to be within the focus of the crystaline humour, as at *a*, Fig. 62; therefore the mind transferring it to that focus, seems to remove it behind the screen *c*. For by the muscles of the eyes they can be turned so that their axis may meet at any convenient distance with the most rapid facility, as at *b c d g*, &c. Fig. 62. But when the mind is careless, or thinking on subjects in which the eyes have no concern, the muscles return to the easiest position, and often make each eye look a different way; so that the object *g* would be seen double, as *g g*.

4th. Radiant rays issuing from a cloud, seem as if the sun was in the cloud; but this is one of those celestial deceptions to which the eye is very liable. When the sun is behind a cloud of various forms and thickness, rays issue from it, as Fig. 58: these rays are reflected from the different parts of the cloud in various angles, yet all appear to the eye as if perpendicular to it, though some of them approach it almost in a direct line; for the eye being less accustomed to contemplate celestial than terrestrial objects, it judges very erroneously of both distances and directions. Suppose the ray *a b*, Fig. 59, issuing from the luminous point *a*, and coming obliquely towards the eye *c*, the eye would foreshorten it into the line *a d*: hence the radiant appearance of rays in the moisture that surrounds the cloud 58.

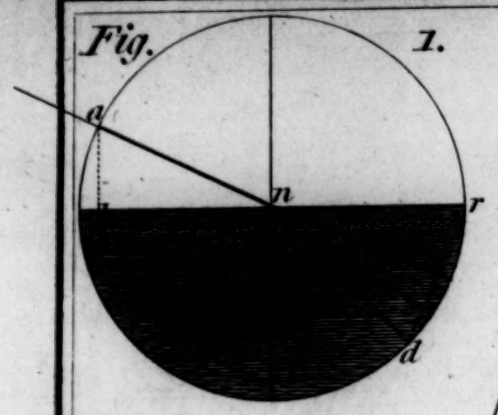
5th. Thus are the short rays, reflected from the moist and polished

edges of the eye-lids, lengthened, when they are nearly closed, and the eye directed to a single candle, about six feet distant. Let *a c*, Fig. 60, be the lids half-shut; then will the rays *a b* fall obliquely on the surface *a*, and be from thence reflected through the crystaline humour to the retina at *d*: the rays *b c*, in like manner, will spread on the retina at *e*. But seeing every thing along those lines that approach the retina last, the rays *d a* produce the unsteady spectrum *g b*; and the rays *e c* the same, in the direction *h b*; growing longer or shorter, as the eye opens or shuts.

6th. From the colour of shadows on a white ground, the colour of mountains seen at a distance, and what is called blue sky, it appears, that the colour of the atmosphere is a diluted blue; a colour that can only be perceived, when large masses of the air are looked through: hence the earth seems surrounded with a sky of a blue colour; and painters give their distant mountains that hue. A very surprizing effect of shadow is produced by placing a red flat piece of glass, *a*, Fig. 61, before the candle *d*, and holding a pencil, *c*, between it and the sheet of white paper *x x*. If another candle, *g*, be placed a few inches from the first, two shadows of the pencil will be produced on the paper, *x x*; that from *d*, through the red glass *a*, viz. *e e*, will be a fine green; and that from the candle *g*, viz. *n x*, will be a deep red. Now, that the shadow, *n x*, should be red, is not marvellous, because it falls on a red ground, produced by the red glass, *a*; but why the interception of red light should produce a green colour, on a white or any other ground, is a phænomenon in Optics not easily to be accounted for. A mixture of blue and yellow makes a green; and the intermediate colour is always formed by the mixture of those that go before and after it, in the prismatic order, so as to reduce the seven to three

primitive colours. If strong white light be looked at through blue glass it will appear green; as in holding up the glass before a dull sky, &c. Black and white, mixt on a pallet, produce a dirty blue; and the blue sky has been supposed to be so produced, by the eye mixing the white of the atmosphere with the blank supposed to exist above it. Now, as shadows on a white wall are of a dubious blue; may not that colour be the result of white light passing through a blue medium? and the near approach of blue and green to one another, make one, sometimes, to be mistaken for the other?

Fig. 1.



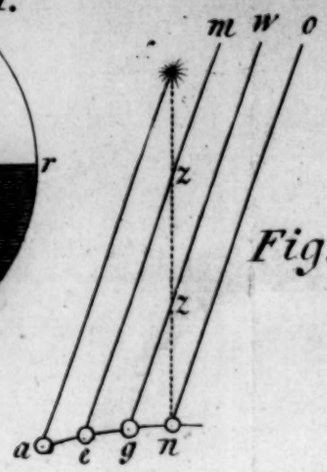
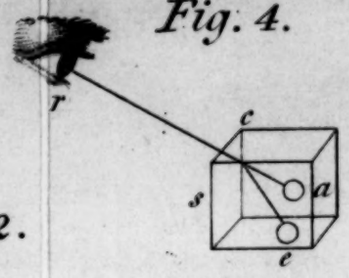


Fig. 2.

Fig. 4.



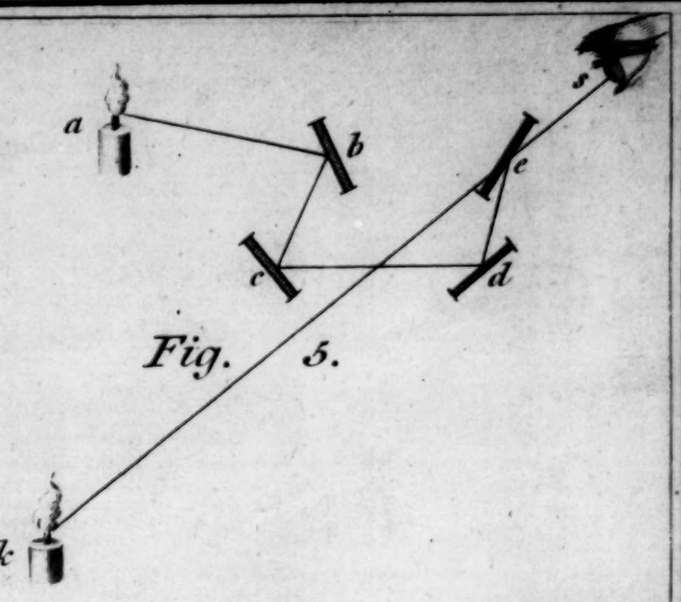


Fig. 5.

Fig. 6.

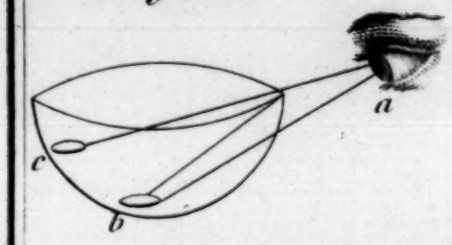
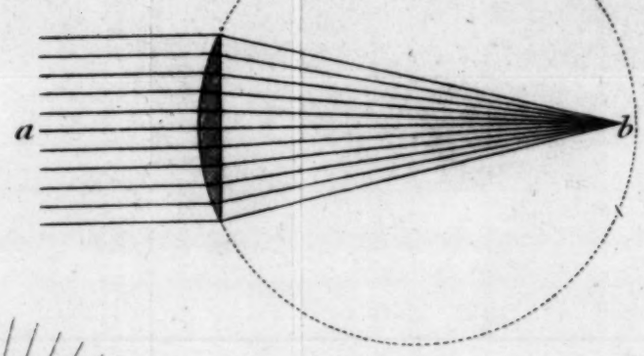


Fig. 7.



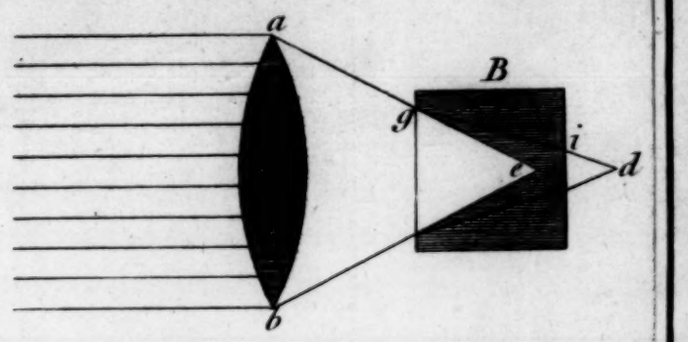


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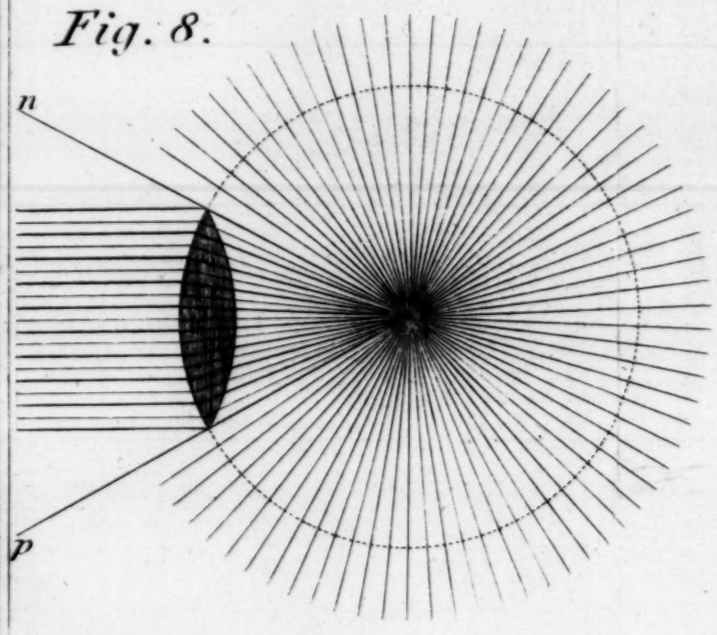
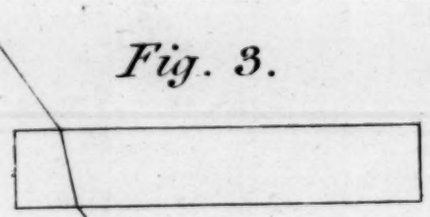


Fig. 3.



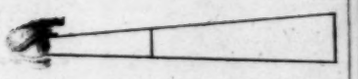


Fig. 11.

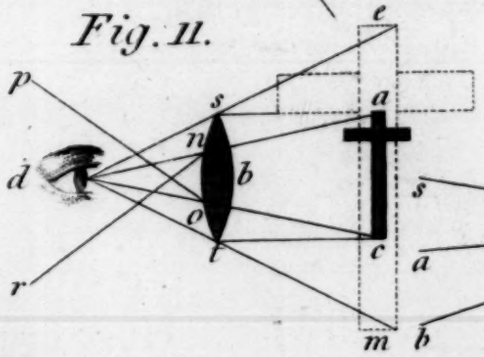


Fig. 13.

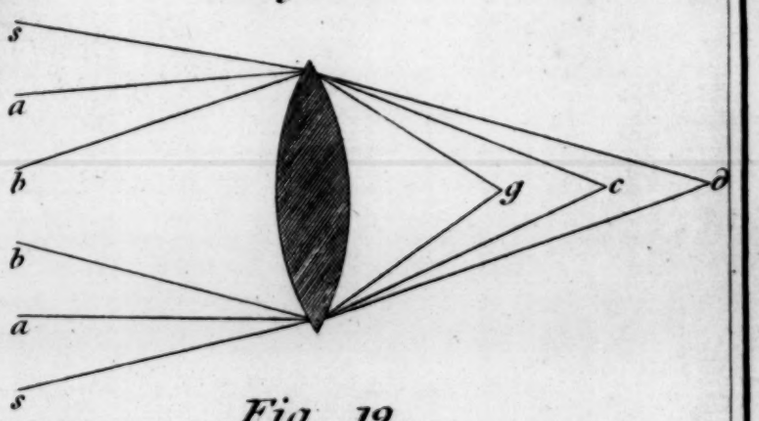


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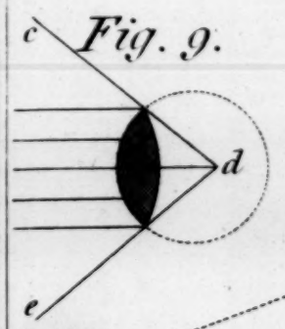


Fig. 10.

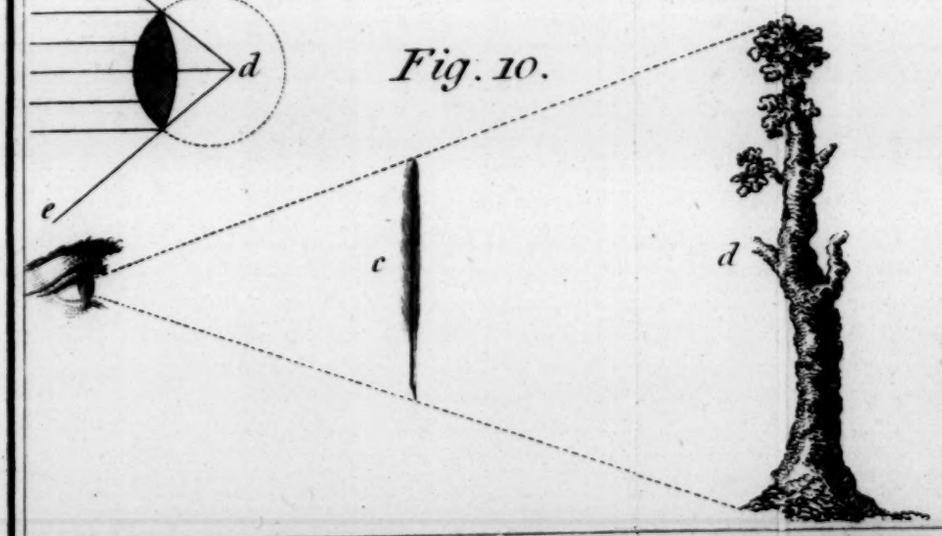
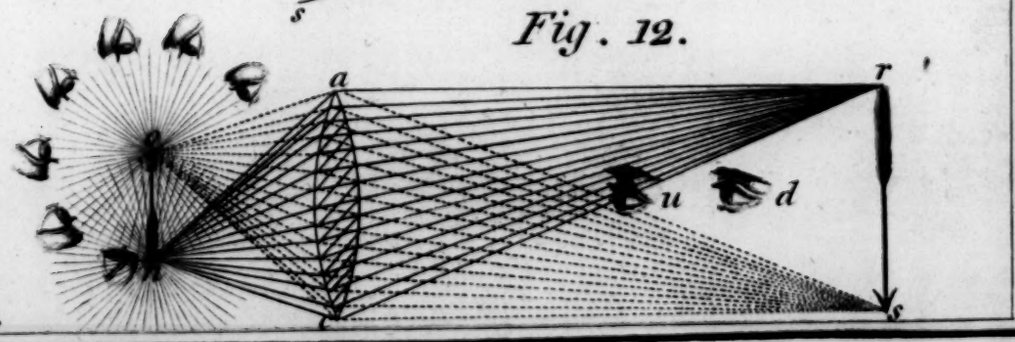


Fig. 12.



Barlow sculp.

Fig. 16.

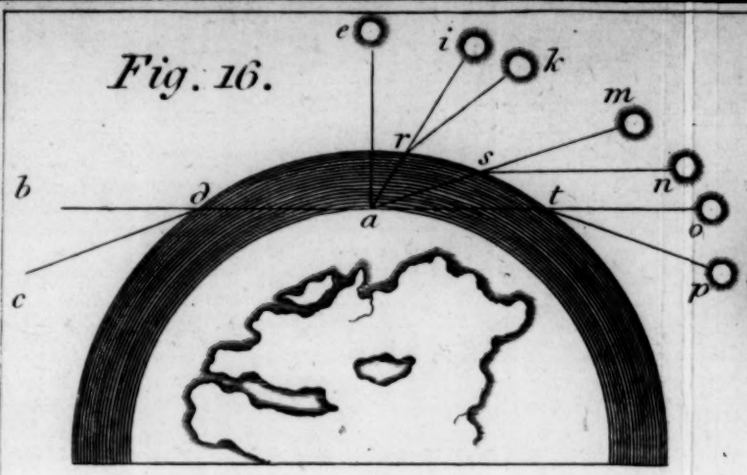


Fig. 17.

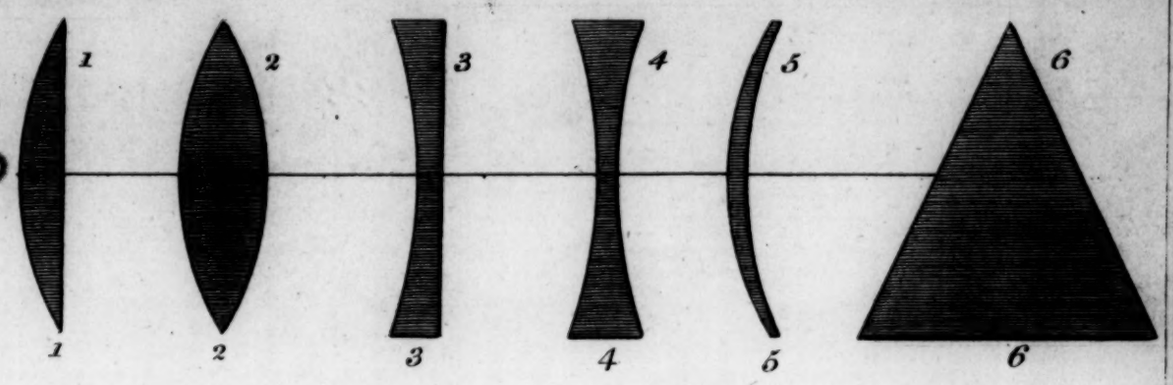


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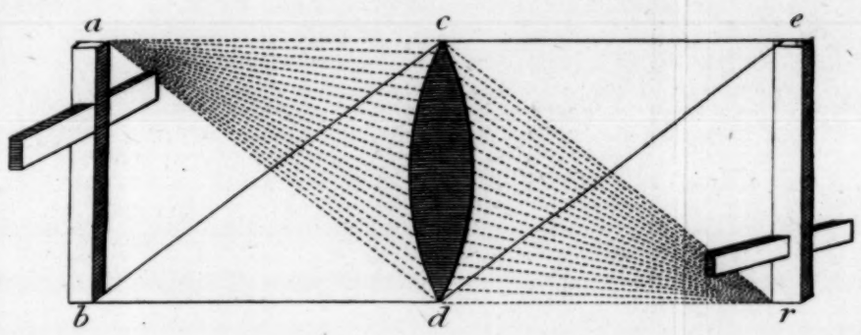


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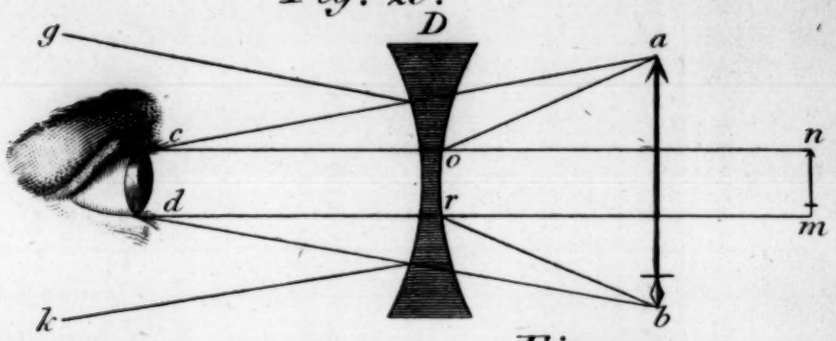


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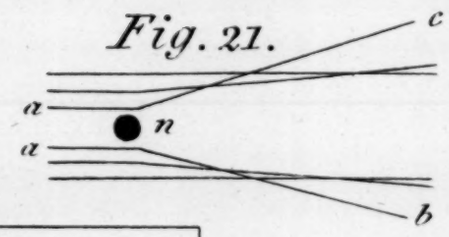


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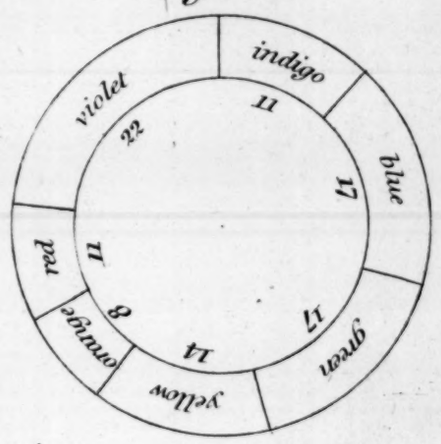


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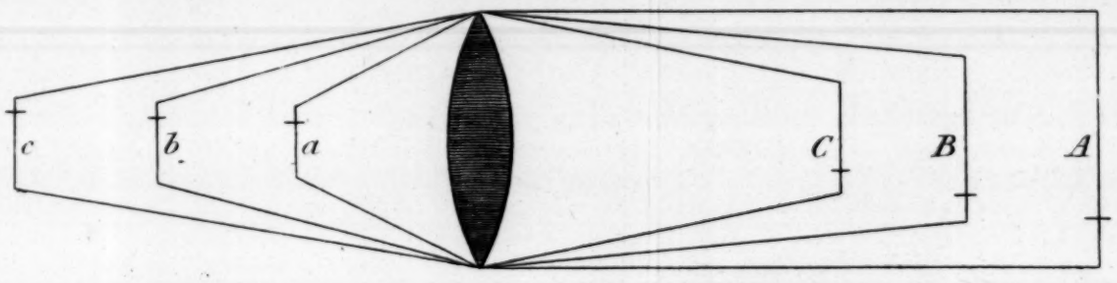


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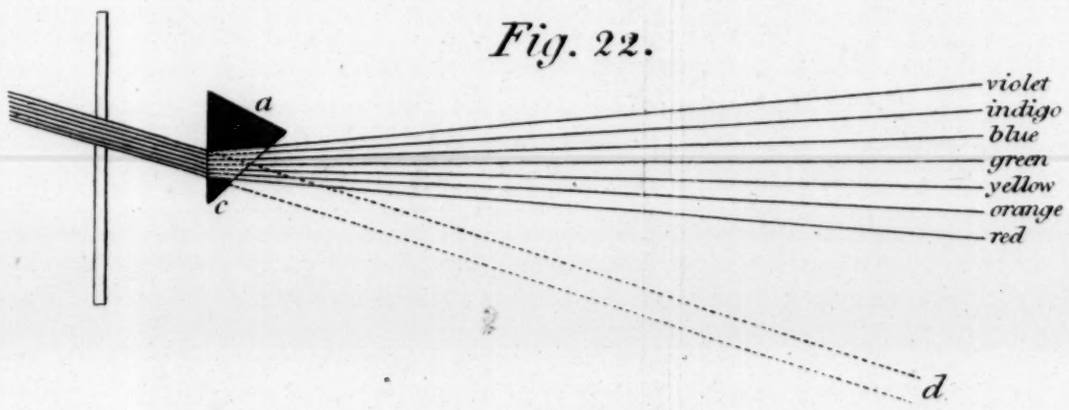


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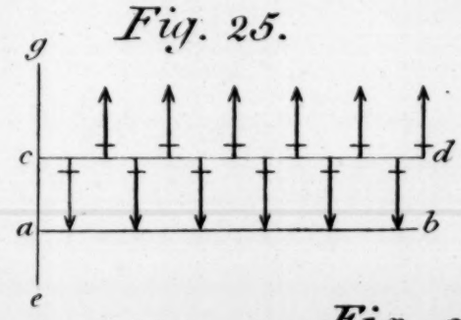


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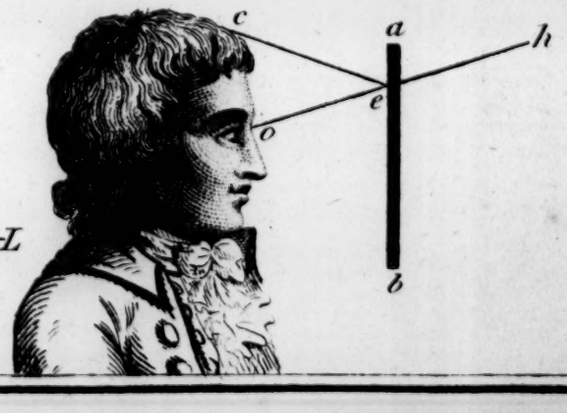
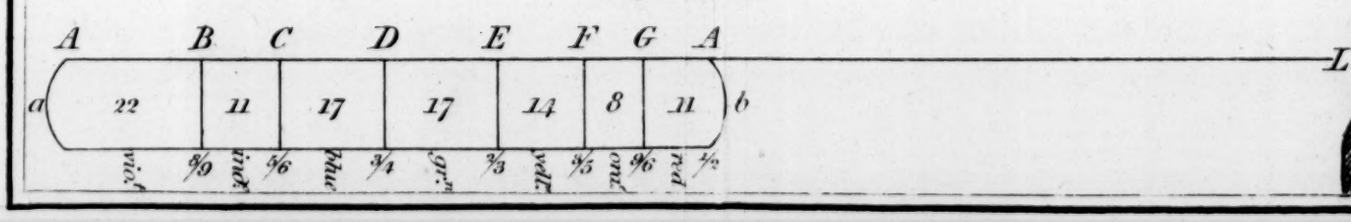


Fig. 23.



Barlow sculp.

Fig. 27.

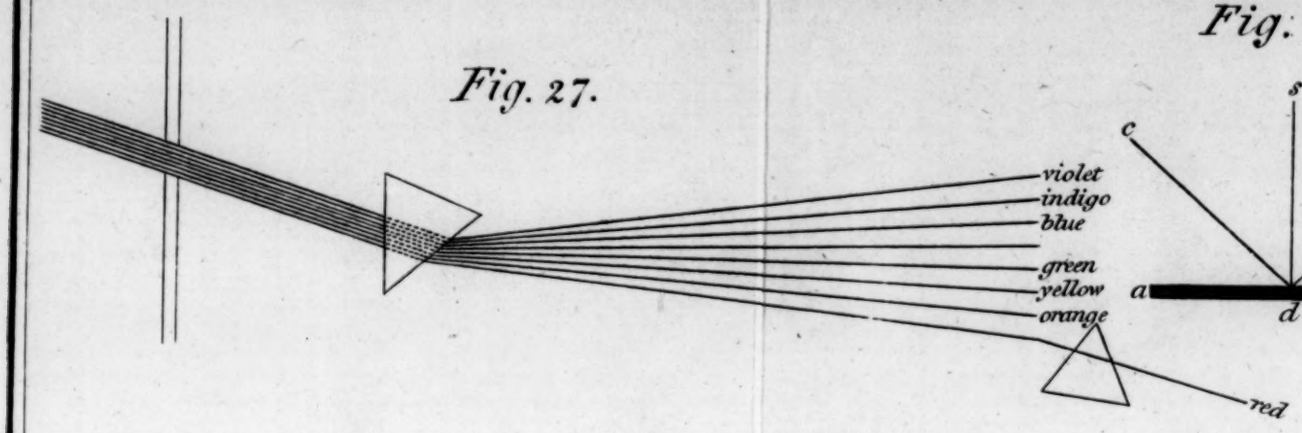


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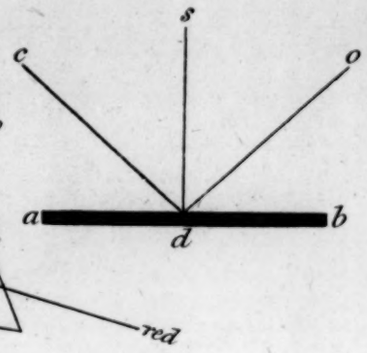


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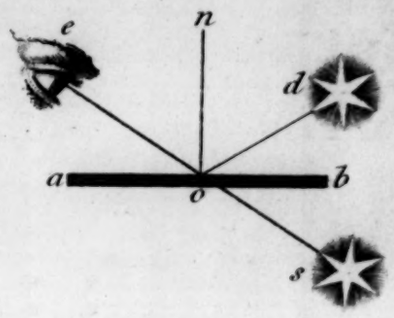


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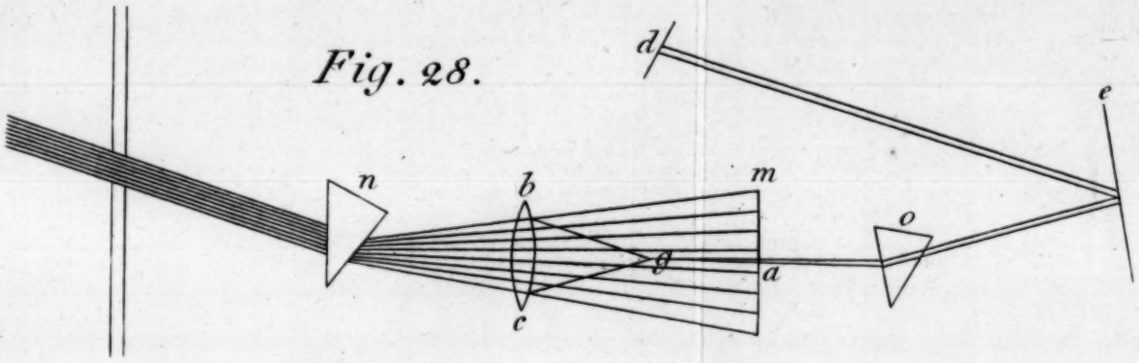


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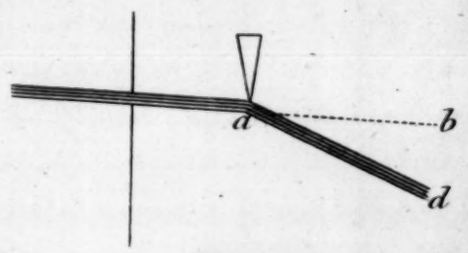


Fig. 31.

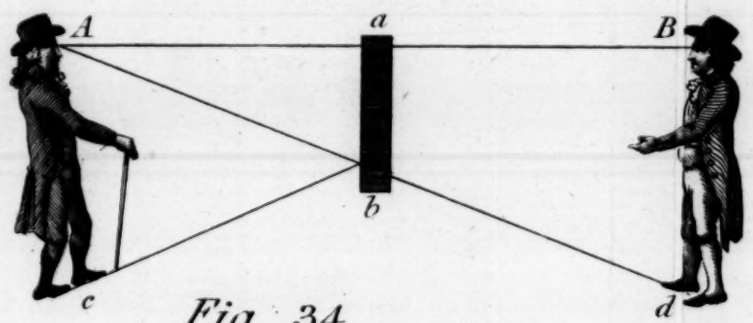


Fig. 32.

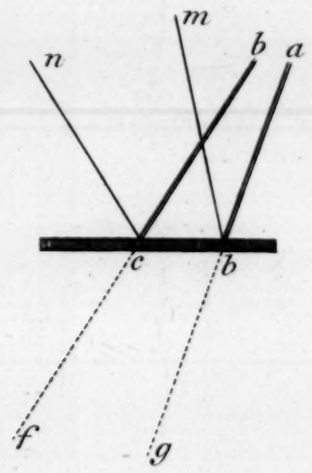


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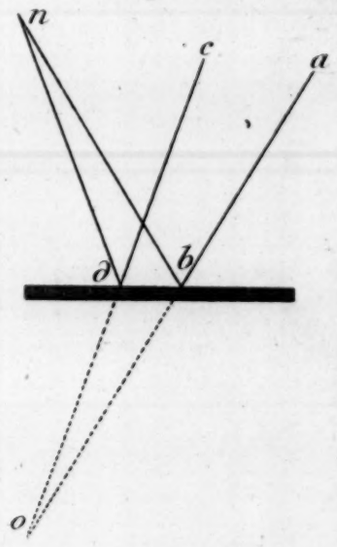


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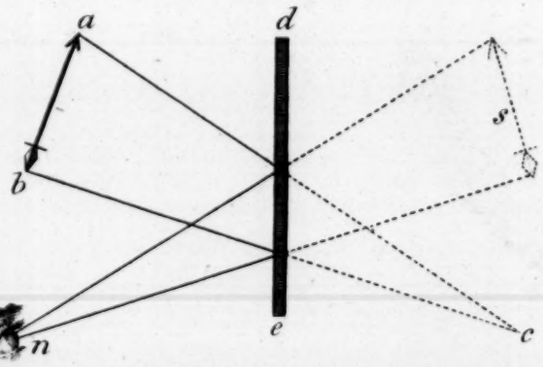


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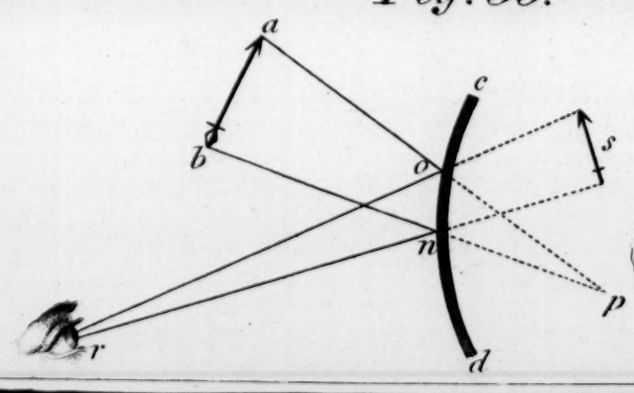


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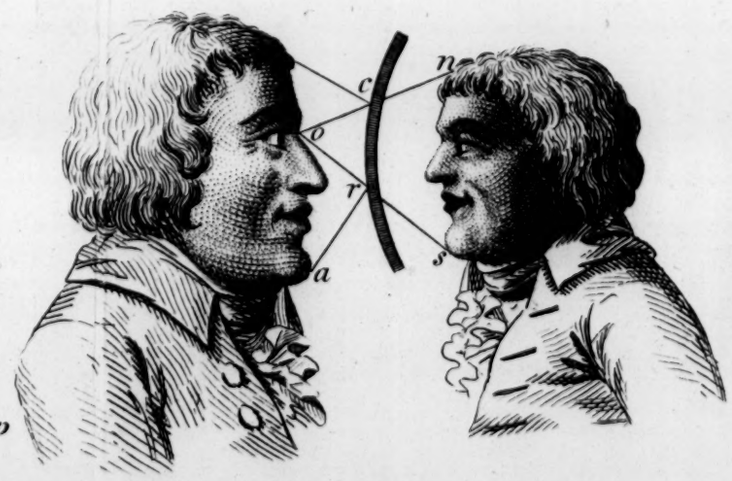
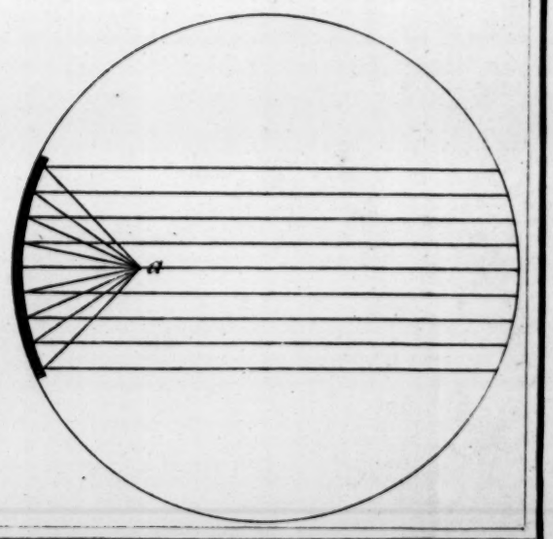


Fig. 37.



Barlow sculp.

Fig. 38.



Fig. 39.

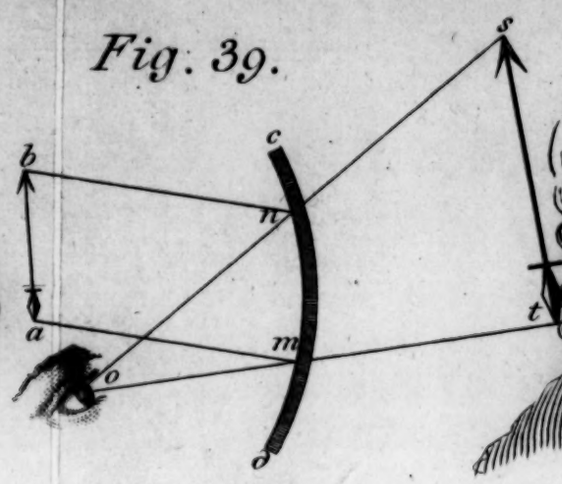


Fig. 42.



Fig. 40.

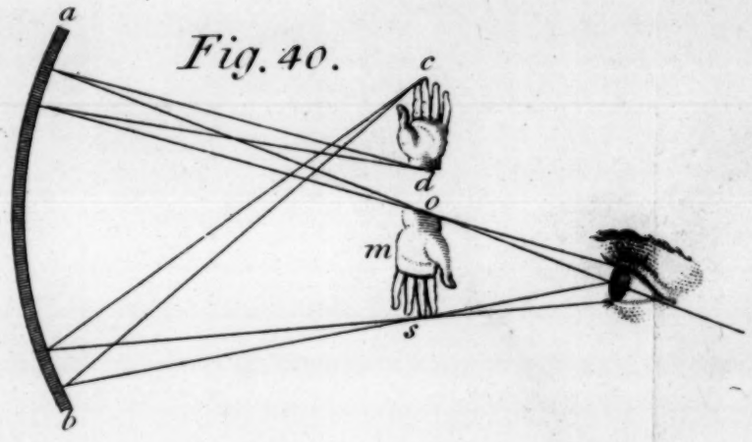
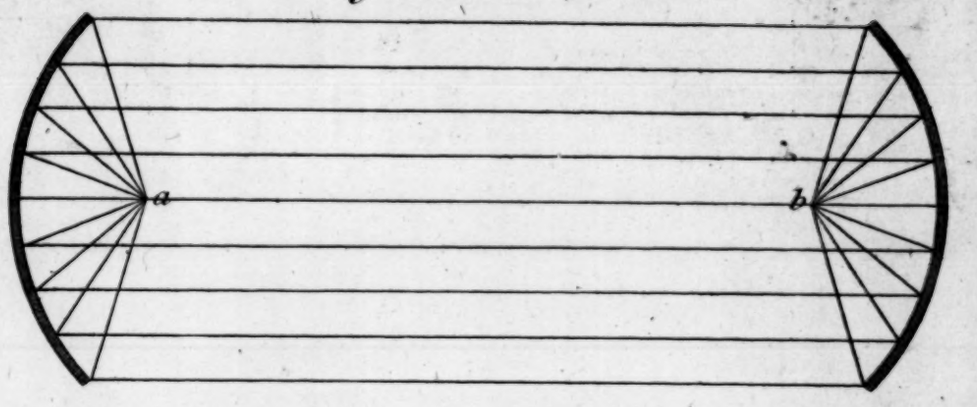


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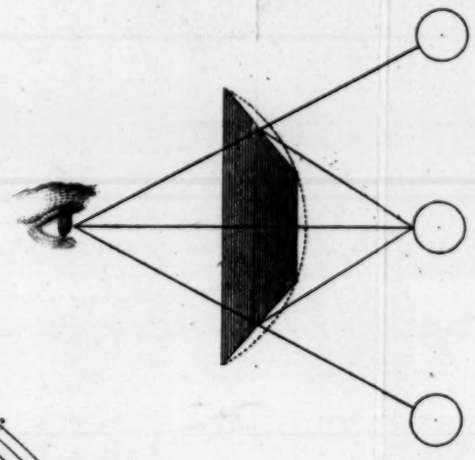


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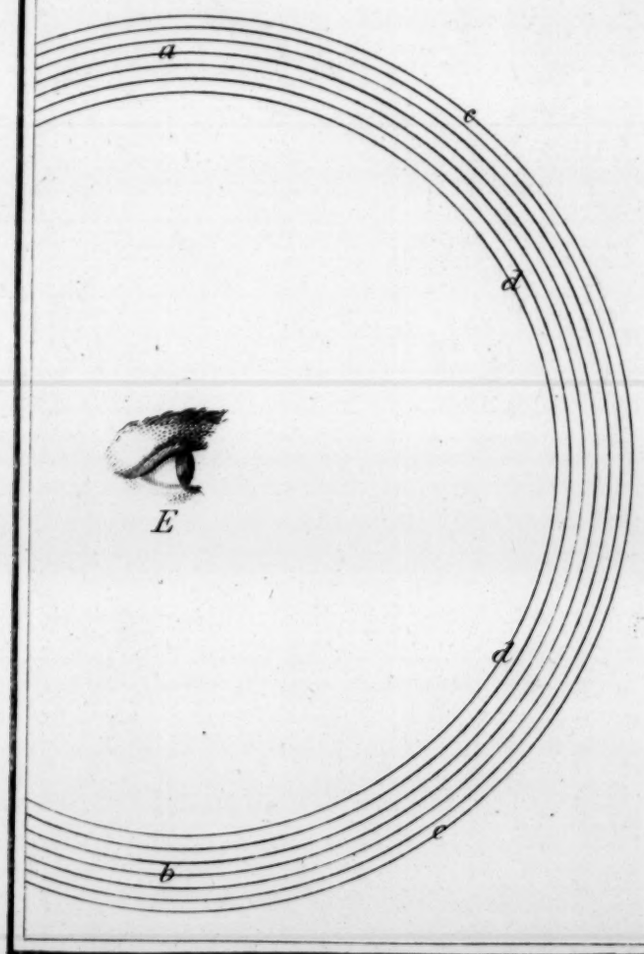
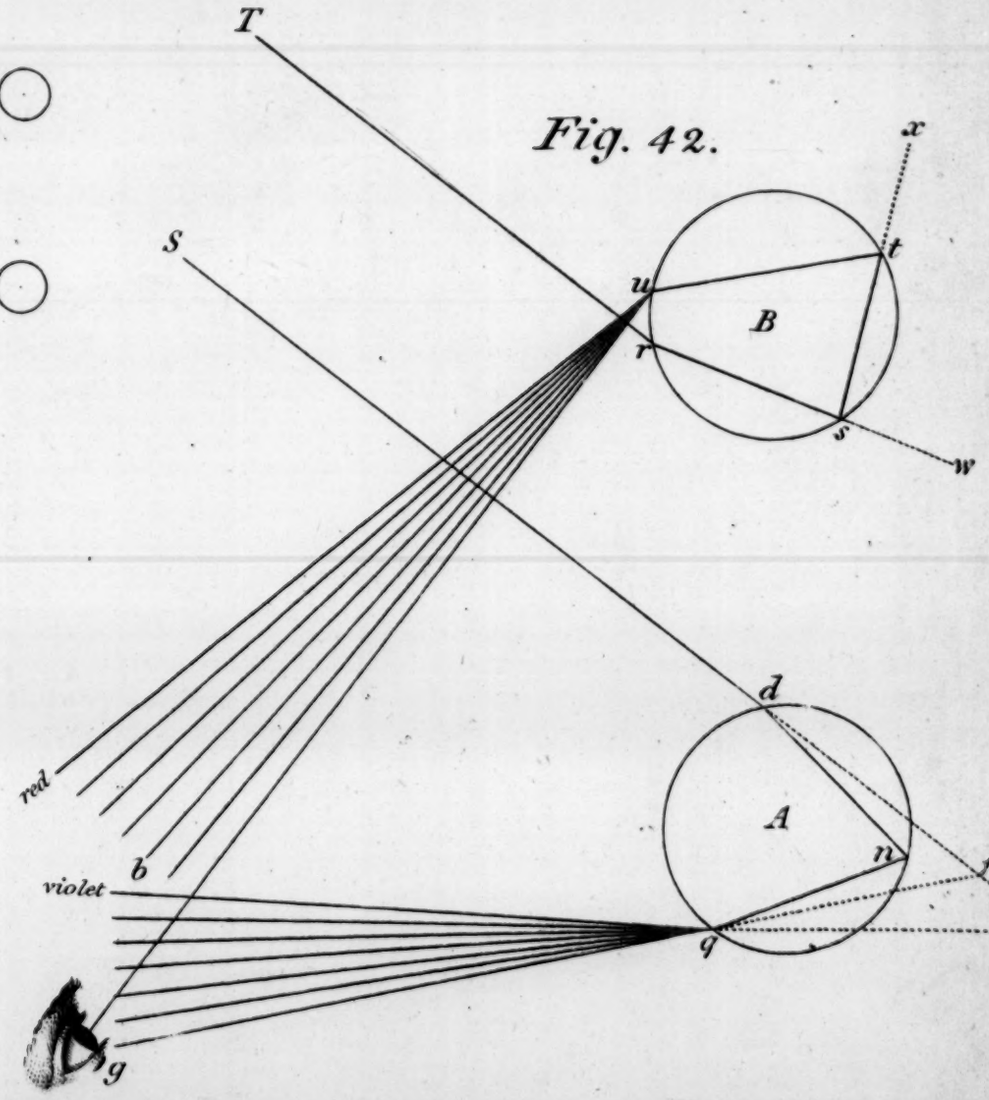


Fig. 42.



Barlow sculp

Fig. 44.

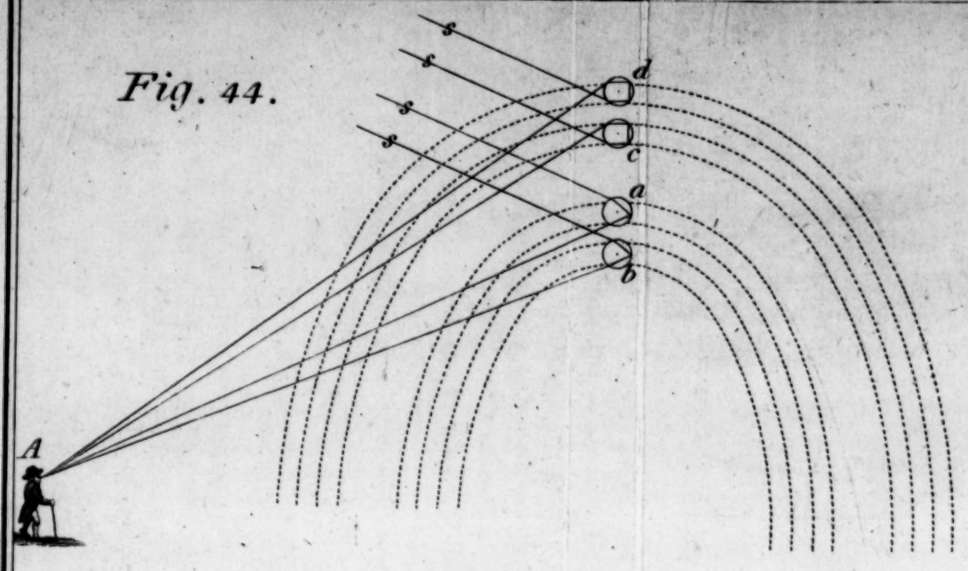


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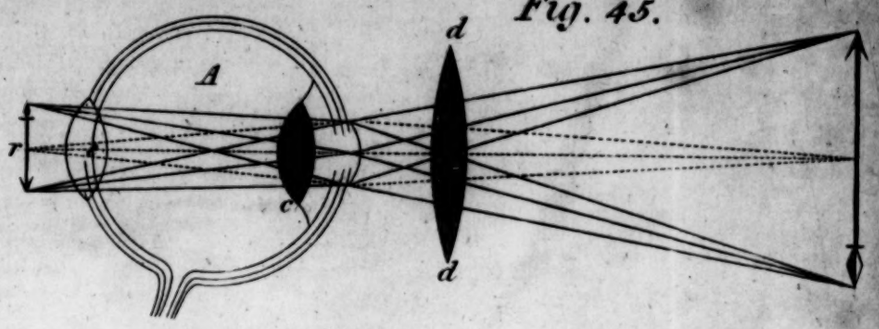


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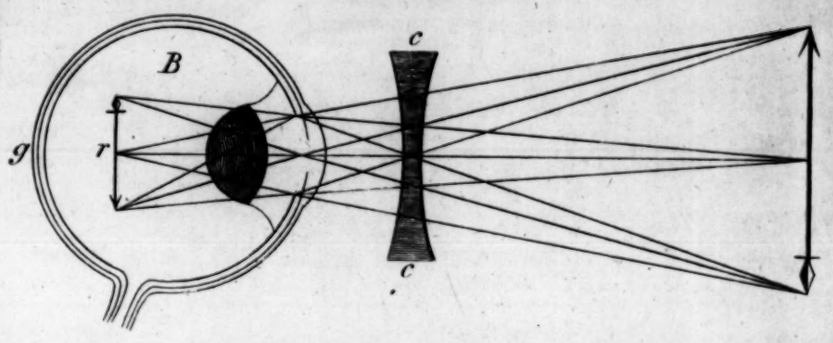


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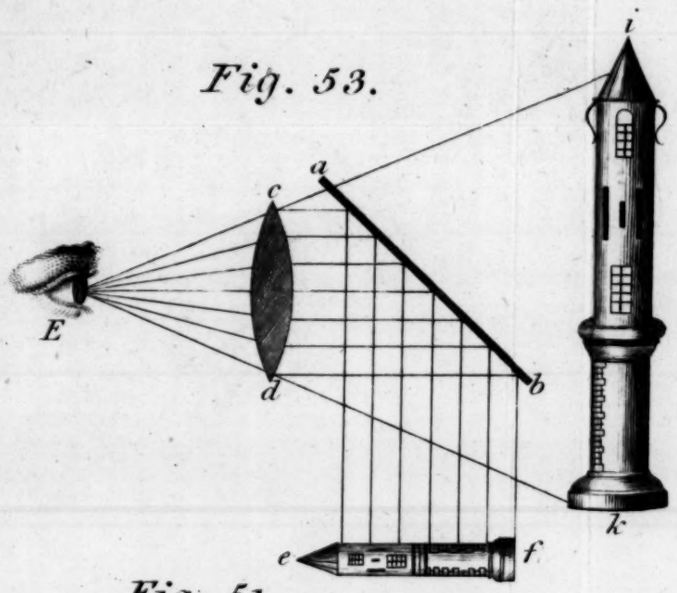


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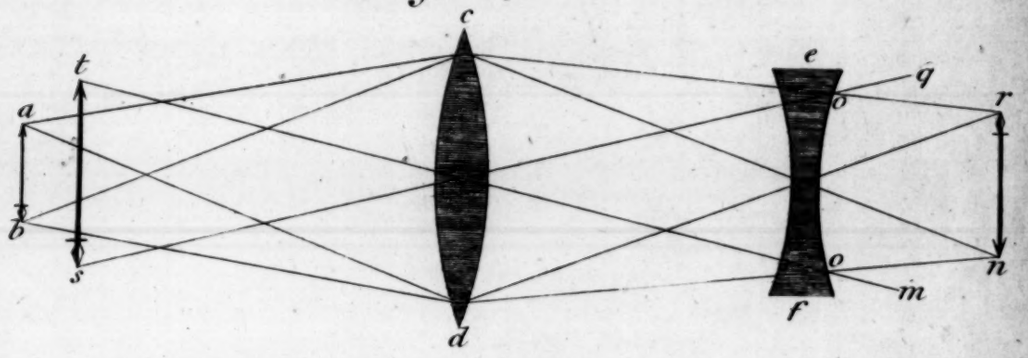


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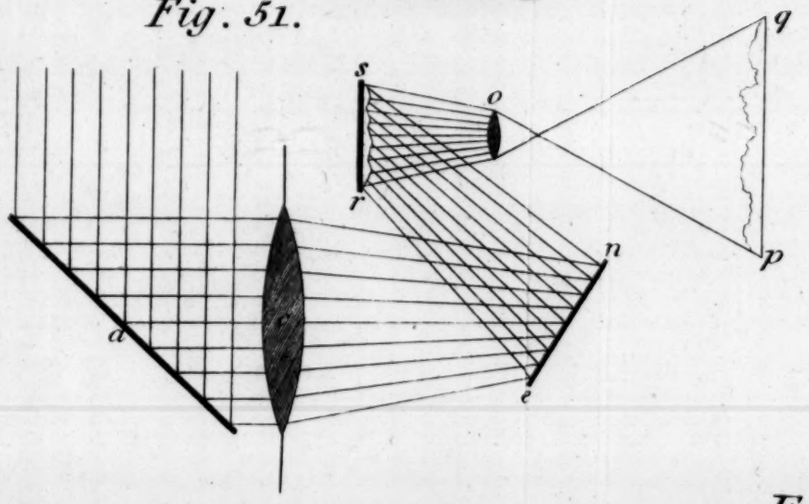


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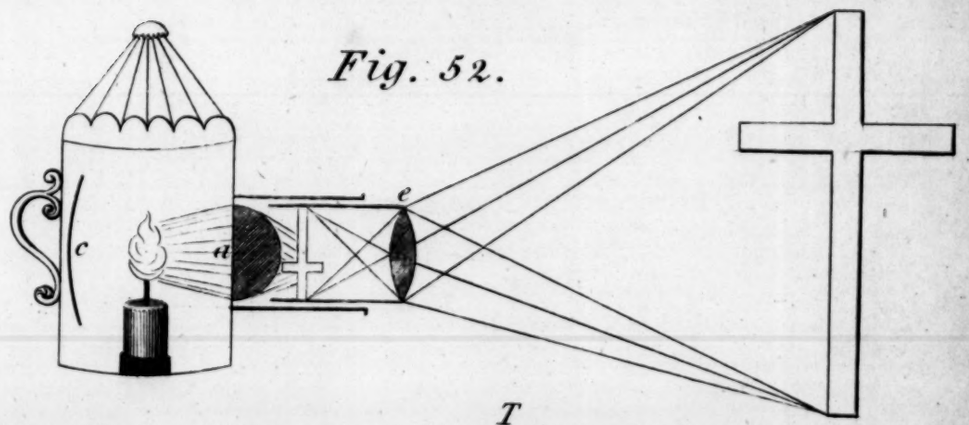
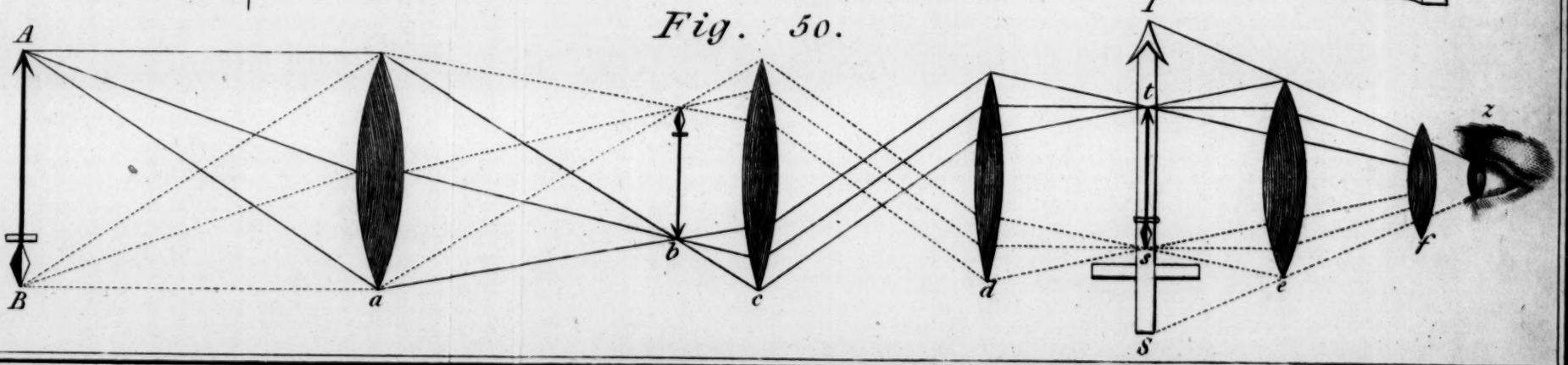


Fig. 50.



Barlow sculp.

Fig. 60.

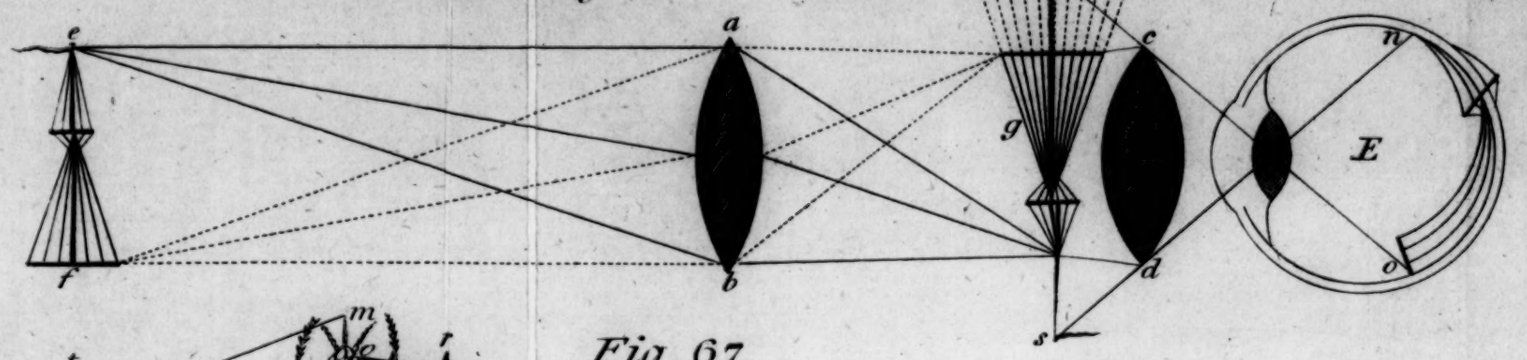


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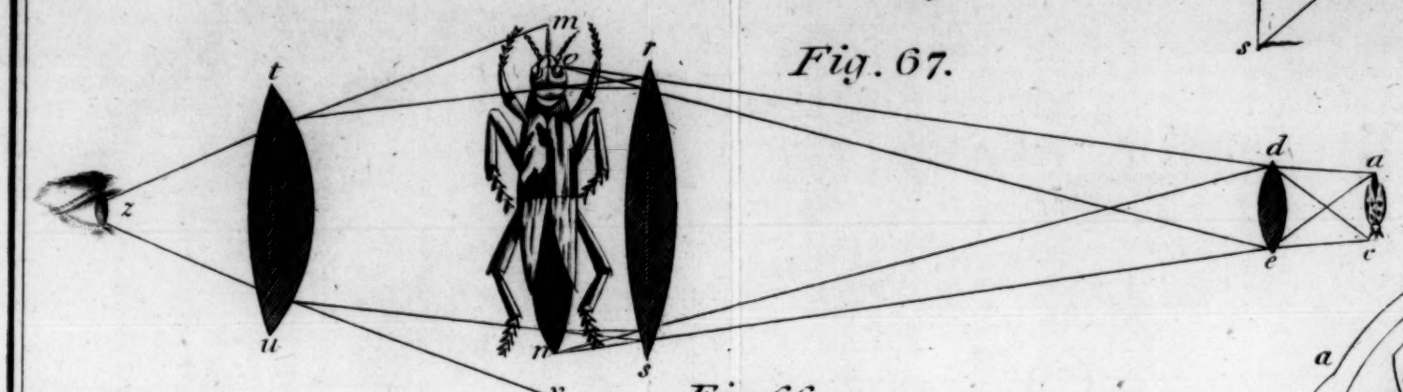


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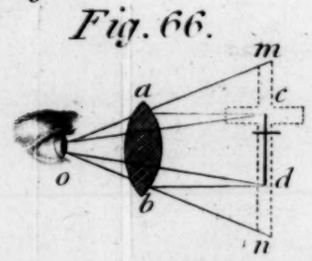


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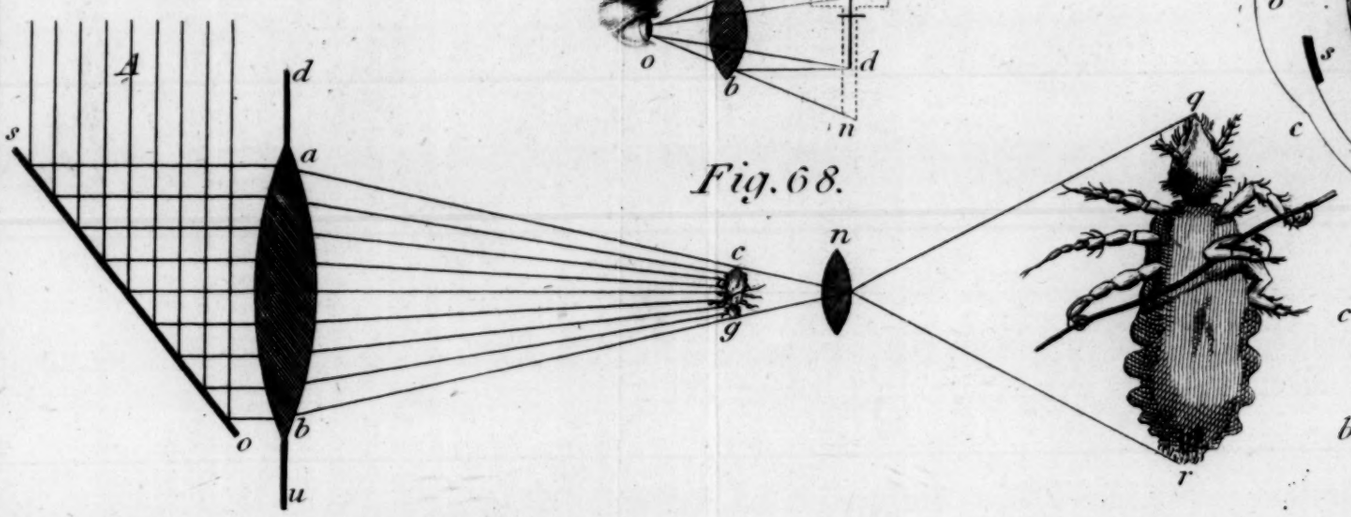


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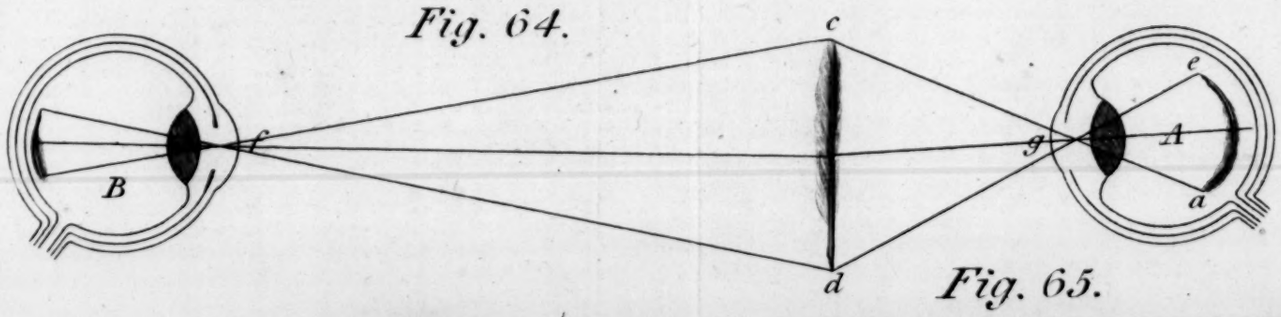


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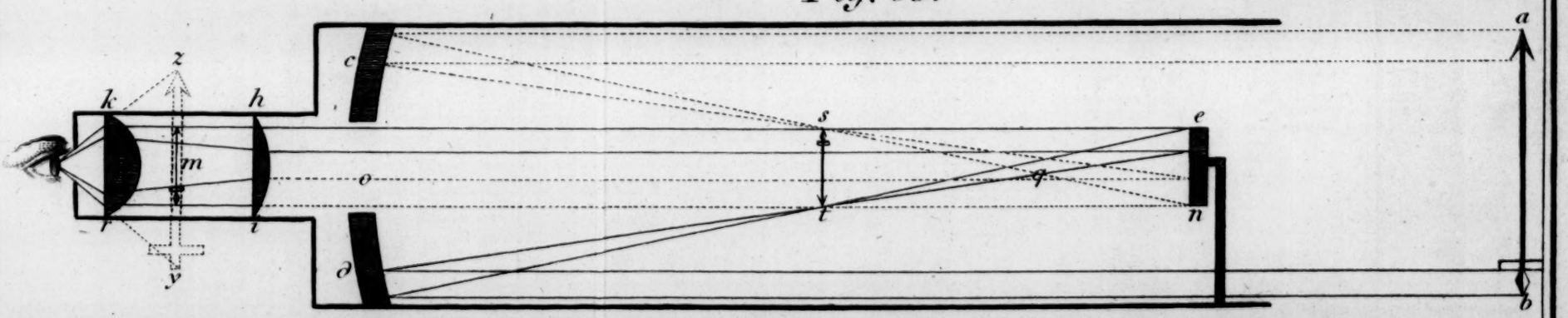


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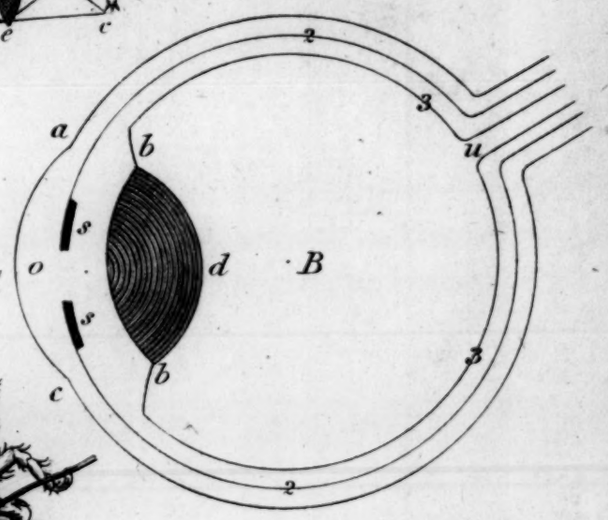
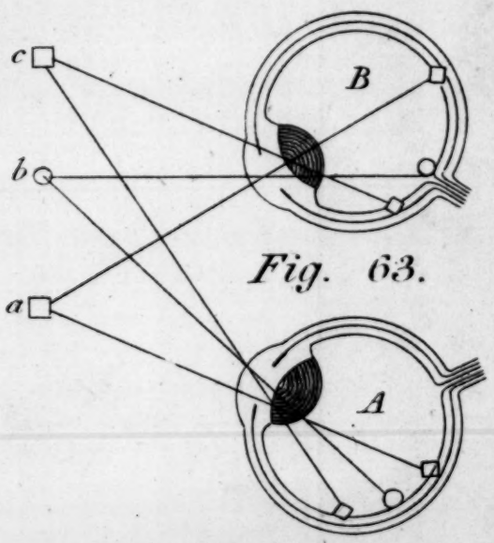


Fig. 63.



Barlow sculp.

Fig. 55.

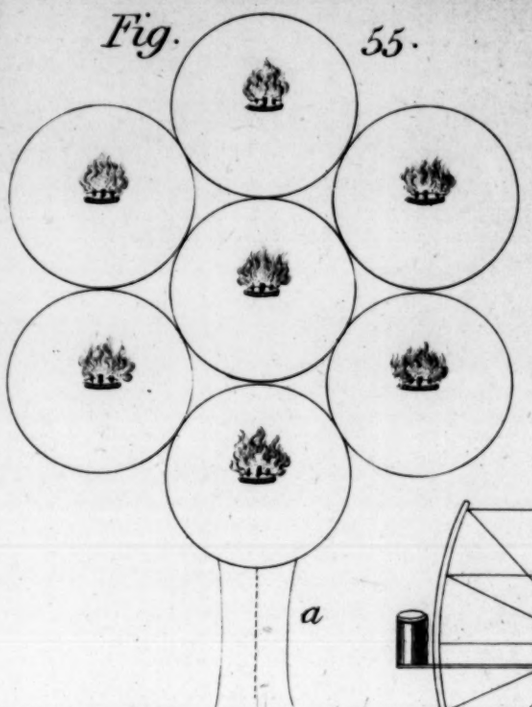


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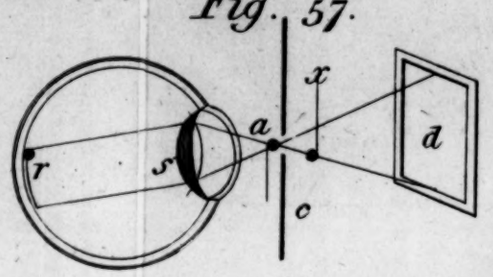
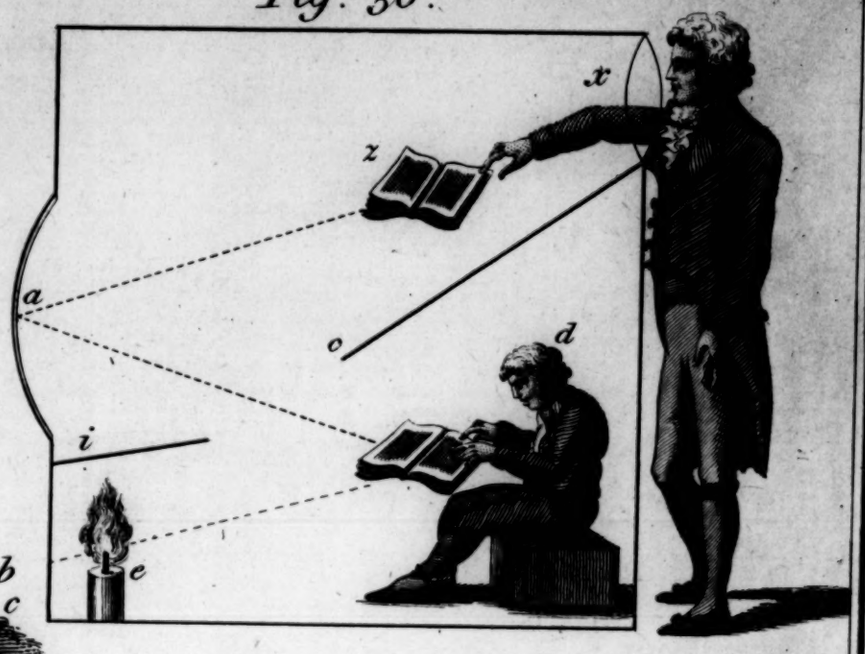


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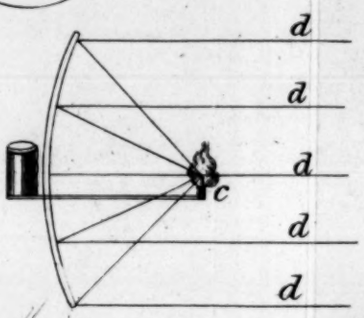


Fig. 59.



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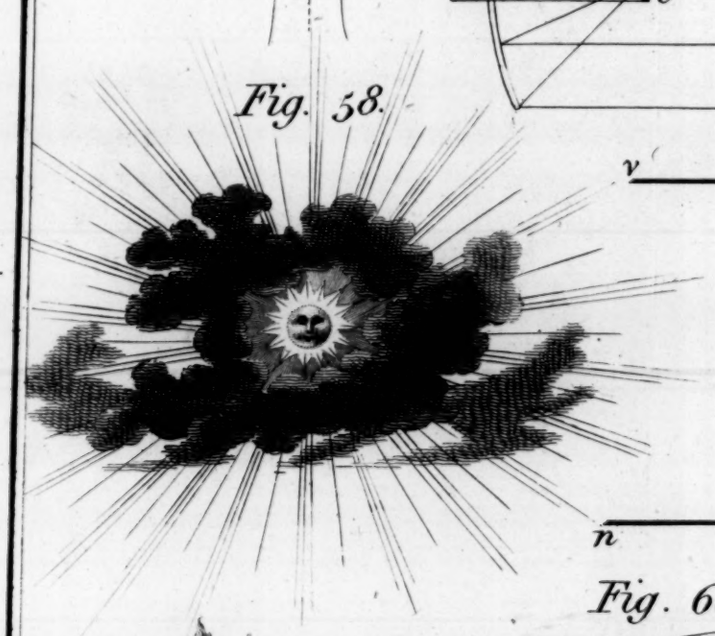


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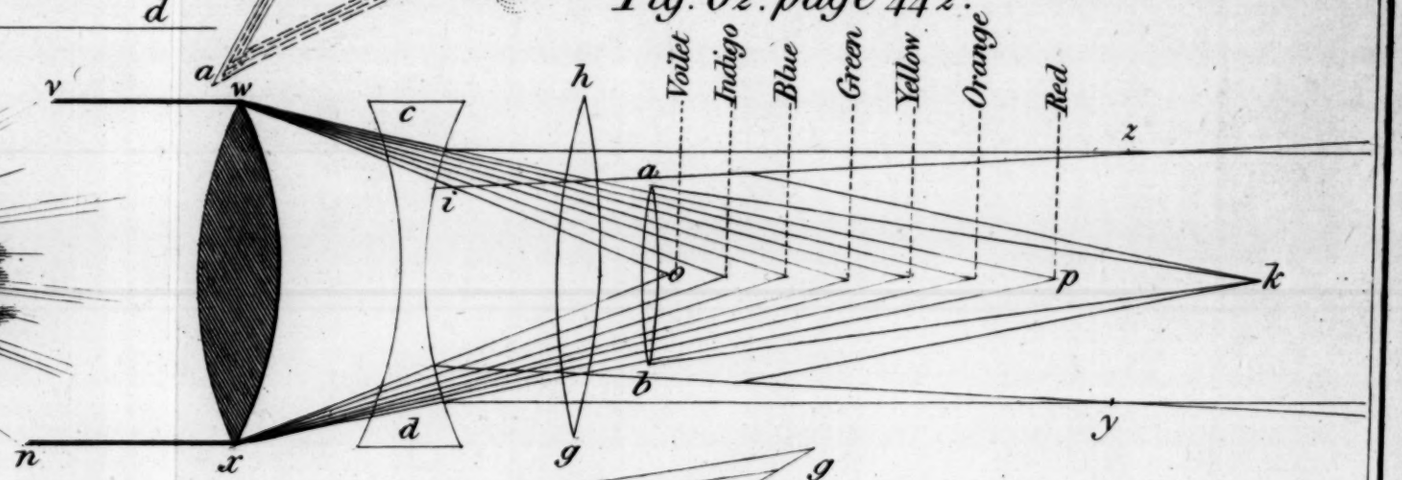


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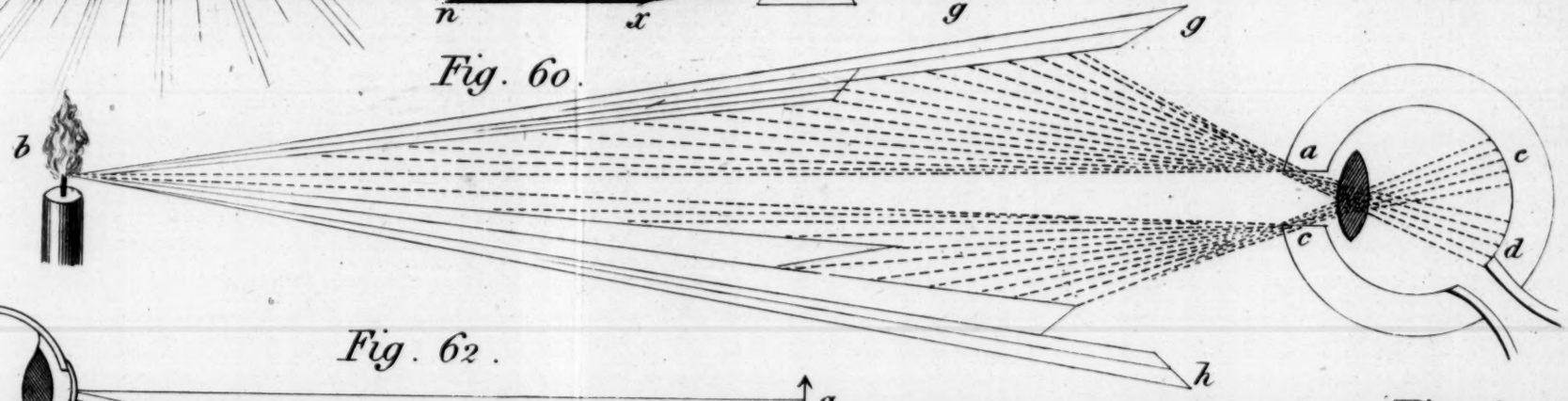


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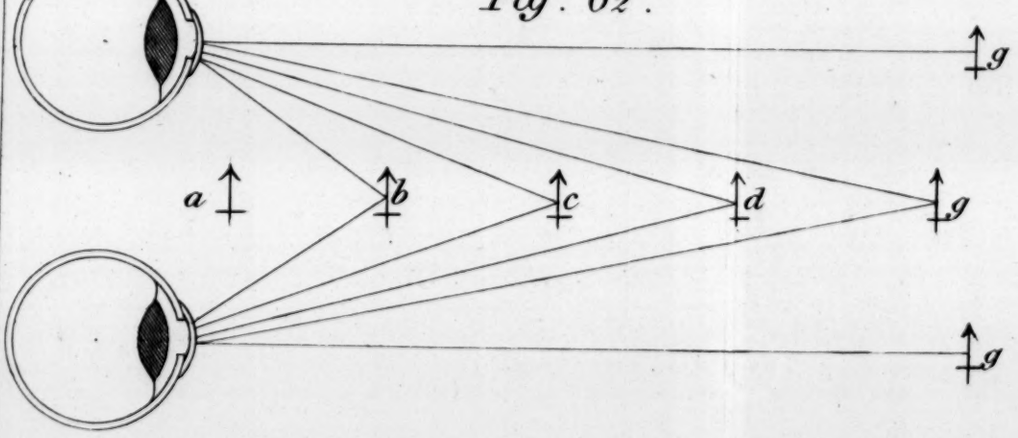
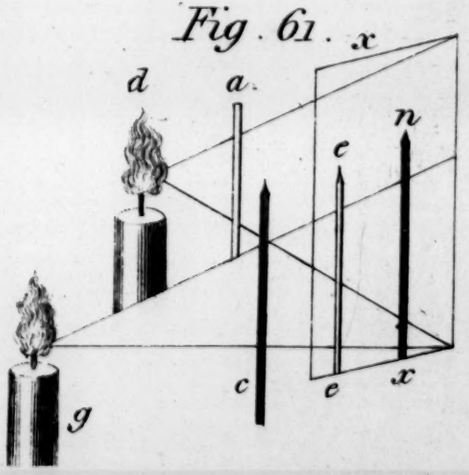


Fig. 61.



Barlow Sculp.

LECTURE X.

ASTRONOMY.

SECTION. I.

HAVING considered the materials of which our globe is formed, it is in the next place requisite that we should consider it as part of a system; the study and knowledge of that system, with the starry heaven that surrounds it, constitute the noble science of astronomy: a science that has engaged the study and admiration of the first characters in all ages of the world;—and is probably the first that ever was cultivated by mankind. For in the first ages of the world, when the business of the human race was to tend their flocks and herds, by night as well as by day, it is natural to suppose, when they had no other object to look at, they would turn their eyes towards heaven: and we accordingly find, in the remotest ages, that a planet was known from a fixed star. But in those times the uninformed mind saw divine vengeance in an eclipse; and destruction in the tail of a comet: and priests and empirics, availing themselves of so natural a superstition, contrived the fallacious and wicked impositions of astrology; by which the credulous vulgar have been the dupes of impostors, who pretended to foretel future events by

the positions of the planets. Had a knowledge of the regular and orderly motions of the heavenly bodies done nothing more for mankind than expose and confute these delusions, and wean the enquiring mind from superstitious fears and uncertainties, humanity ought to have bowed to a telescope, and made the pillar of a quadrant an altar whereon to sacrifice its terrors and ignorance! But these illusions are happily done away by this enlightening science; and we can now look on comets and eclipses with tranquillity.

In measuring time (so necessary in all human affairs), we have no invariable standard but in the heavens. In chronology, the dates of some of the remotest events of antiquity are well ascertained by the eclipses that happened about the time. But the most important use of this science, is, that of teaching the adventurous navigator how to find his way over a trackless ocean. So that we may say, that the riches and comforts derived from trade and commerce are in a great degree owing to this science. By it also is ascertained the true figure of the earth; and the situation, shape, and extent of its continents and seas. But of all the means by which mankind have been led to a knowledge of the Deity, this science undoubtedly affords the most conspicuous! A view of creation, through the eyes of astronomy, at once astonishes and overwhelms the mind! The grandeur of such a spectacle, accompanied by an idea of that omnipotent Power, which made and governs the whole, exalts while it chastens our faculties; inspires humility, while the understanding is strengthened and enlarged; and finally leads us to a rational conception of the attributes and perfections of this great and good Being.

Before we launch out into that space which surrounds us on all sides, it may be necessary to take a survey of this planet on which

we live. Antiquity believed it to be a flat plane; and almost in our own time, the church consigned a sage to prison, for teaching that it was a globe. But the many voyages that have been made round it, have proved its globular figure beyond all doubt. This may be easily perceived without performing such a voyage; for when we first see a ship at sea, her topmast alone appears, as if sticking out of the water; as she approaches nearer, we see her upper sails; after a nearer approach, we see her lower sails; and soon after the hull itself. We should certainly have seen the whole at once, had she been approaching us on a plane; but it is evident that a bulging portion of the sea intervened, which hid her from our sight, until she came so near to us as to be on a comparative flat. The young astronomer will have his conception assisted by inspecting Fig. 1. where the curve line *a b*, represents a portion of our globe's surface. The ship *a* would be altogether hid from the spectator *c*, except its topmast, which would be seen along the line *d n*; when the ship arrives at *g*, her lower sails would appear to the spectator *c*, above the line *d s*; and when she comes to *m*, she would be entirely seen.

In like manner, when we sail from great capes, or headlands, we lose sight of those eminences, first at the bottom; then the middle disappears; and soon after, the top: in approaching the land, the tops of the mountains first appear; then the middle of them; and when very near, the flat shore itself. These appearances are universal: and prove that we always sail upon a globular surface.

An eclipse of the moon, is occasioned by her passage through the earth's shadow; now this shadow appears always circular on the moon's face, whatever side of the earth is turned towards her: shewing, that it is not a flat round body that projects the shadow, but a globe.

If we may be permitted to judge of this matter analogically (from that sameness that runs through all nature), we can prove the sun, moon, planets, and fixed stars, all to be globes. Can we see any reason, why the Almighty ſhould invert the general order and economy of the universe, for this speck of earth on which we live, and which bears but an insignificant proportion to many of the bodies in our own system?

A pendulum vibrating slower at the equator than in France, first gave the hint, that the earth was not a perfect globe. But as heat expands metals, this might be supposed to occasion the difference. A rod of iron, thirty feet long, will not expand above one-tenth of an inch in the hottest summer's day; but a pendulum rod of 39.2 inches, which vibrates seconds at London, muſt be shortened one inch to vibrate seconds at the equator; therefore, gravity muſt be less, or the centrifugal tendency more: the latter is the cause; and it has been calculated that a body weighing 289lb. at the pole, would weigh only 288lb. at the equator. For the equatorial parts of the globe describe so large a circle round the earth's axis every twenty-four hours, in comparison of the parts nearer the poles, that the tendency to fly off not only diminishes the weight of bodies there, but has made those parts swell into a protuberance, that distorts the simple and beautiful figure of a globe, into that of an oblate spheroid, or that of an orange or a turnip. It was calculated by Newton, that this swelling would increase till the equatorial diameter should be to the polar as 230 to 229, when it would stop, and become a balance to the power of gravity. It should seem as if this must have taken place when the materials of the earth were in a soft or pulpy state, and mixed together, ere land and water were defined or separated. The fact, however, has been proved by actual mensuration, that the earth is about thirty-five miles in diameter from one side of its equator to the other,

more than it is from pole to pole. Here we have a wonderful specimen of human genius and invention! A pigmy of ſix feet, undertakes to ascertain the true figure of a body 8244 miles in diameter! The places ſelected for this ſingular meaſurement, were under the equator in South America, and under the polar circle in Lapland. To give a general idea of it, we will ſuppoſe I want to know the diſtance of *a* and *b*, Fig. 3: either upon a plot of ice, or on level ground. I meaſure exactly a line that I make the base of a triangle; ſuppoſe that base to be *c d*. Stations muſt now be fixed upon in the neighbourhood, within ſight of one another, ſuch as churches, tall trees, flags on the tops of the hills, as *a*, *e*, *b*, &c. With a quadrant or theodolite at *d*, the angle *a d c* is taken*; and at *c*, the angle *a c d* is taken. The angles, and one ſide of a triangle being known, the length of the other two ſides will be found by a ſimple process in plane trigonometry: having thus found the length of the line *a c*, I make it a base of the new triangle *a c e*. Taking the angle *e a c* at *a*, and the angle *a c e* at *c*, I become poſſeſſed of the length of the line, *a e*: this line I alſo make the base of a new triangle, viz. *a e b*. By taking the angle at *a*, and that at *e* as before, I acquire the length of *a b*, the line ſought. This may ſerve to give a general idea, how inaccessible diſtances may be found, and how the mathematicians proceeded at Quito, and in Lapland. But when a line is thus meaſured on the meridian, or immediately north and ſouth, how is this to aſcertain the true figure of the earth? Suppoſe the diſtance above found, to be an arch of the meridian *a b*, Fig. 2. at the equator; and the arch *c d*, the ſame diſtance, and bearing, at the polar circle. Now a plummet if ſuſpended at *a*, would point to the centre of the earth *e*, and alſo to the fixed ſtar *g*. The ſame performed at *b*, would alſo point to *e*, and to the ſtar *m*. Though we know nothing

* When three letters represent the three angles of a triangle, the middle letter is the angle in question.

of the distance of the fixed stars, we can easily draw an imaginary circle through *g* and *m*, and know the number of degrees they are from each other. For all circles, great or small, real or imaginary, are supposed to be divided into 360 parts, called degrees. So we find, with a common quadrant, how many of those parts or degrees are contained between the stars *g* and *m*. This part of the survey being finished, we proceed with the line and plummet at *c* and *d* in the same manner, and find the line point to the stars *i* and *k*. Now, though the terrestrial diſtance *a b* is the same as *c d*, the celestial distances *g m* and *i k* are very different, as may be observed even by the eye. Does not this, at first sight, prove the earth to be flattened at its poles, and protuberant at its equator? or, in other words, that the arch *a b* is a portion of a smaller circle than *c d*, and of course that it will occupy a larger arch in the heavens? These surveys being thus compared, it became easy to estimate how much the equatorial diameter exceeded the polar: which was about 35 miles; the length first calculated by Sir Isaac Newton.

This effect is well represented by two circular rings, flexible, and crossing each other, as Fig. 4: these turning slowly by the handle *a*, will appear like a globe; but if turned swiftly, they assume the swelling oblate figure of the earth.

But the young mind will naturally ask this question: If the earth be a globe, or any other figure like a globe, how can people stand on all sides of it, and believe themselves upon its top? When we first begin to reflect upon this ſubject, we are apt to carry our ideas downward, not only through the earth, but through all space: in respect to space, however, there is neither top nor bottom in it; and on the earth, the whole of its surface is its top, and its centre is its general bottom. Not that we conceive there is an attracting something

there, which draws the materials of the earth toward it, and unites the whole in a dense ball. In a former lecture we have proved that the whole earth is the attracting body, and not any thing placed in its centre. If Fig. 6 represent the earth, with inhabitants standing radiantly round it, the figure *a* will be the moſt powerfully attracted towards his antipode *c*; because there is the greatest mass of the earth under his feet in that direction; and the figure *c* will be the most powerfully attracted towards his antipode *a*, and he would therefore call that direction his downward. The figure *d* is attracted most towards *m*; and the figure *m* most towards *d*; so that if a hole were made through the earth, and they were to fall down it at the same instant, they would meet at the centre *o*, where they would be suspended between contending attractions, and lose all further ideas of downward, being at the general bottom of every place respecting the earth. If they pursued their journey towards their respective antipodes, the rest must be performed uphill, or rather as if they were climbing up the shaft of a mine. At first, indeed, that difficulty would be inconsiderable; but it would increase as they left a greater portion of the globe behind them, until they arrived at the surface, where it would be greatest of all. Is it not evident, therefore, that the whole surface of the earth must be its general top, and the bottom to all parts of it, the centre? So vague are our ideas of upward and downward, that if the planet Jupiter were to approach our world so near that his attraction (from his superior size) was greater than that of the earth; in his approach, we should see him over our heads, and begin to feel ourselves lighter; as he came nearer, we should begin to rise from the earth; presently we should fall to that body we just before had seen above us; and then the earth itself would be over our heads!

It is equally incomprehensible to the uninformed mind, how it is

possible that the earth should turn round its axis every twenty-four hours, and we not perceive it. This, like many other celestial appearances, is fallacious. We see the sun rise in the east, and set in the west. We trust the evidence of our eyes implicitly in near objects, and with difficulty distrust them in those that are remote. But if the earth turn on its axis from west to east, the sun, moon, and stars, must certainly appear to turn the contrary way, or from east to west: therefore those bodies must turn round us, or we must turn round the earth's axis. Let us then enquire which of these is most consistent with that wisdom and simplicity we see in the other parts of creation. Mathematicians can certainly prove the sun to be above a million of times larger than the earth; and nearly a hundred millions of miles diſtant from it. Astonishing! Can common sense believe it possible that this huge globe should revolve round the earth, to give it day and night, with a rapidity exceeding all imagination, when the earth by simply turning round, on its axis, would have all the benefit of ſuch a revolution! a common mechanic would be ashamed of ſuch a machine. Nay, not only the sun, but the whole heavenly host, must make this rapid and unnecessary revolution, was it as it appears to our eyes. We can see the other worlds of our system turn on their axes; and from analogy, might conceive that must be the case with our earth. It is true we feel no jolts or obstacles by which we generally judge of motion, for the earth flies through space like a balloon through the air; where the aeronaut, insensible to motion, transfers it to the towns over which he flies. If we were in the cabin of a ship, when she turns with the tide, on smooth water, and looking at fixed objects at a distance, our eyes would tell us those objects were turning round us, and that we were at rest. So are we deceived in the motion of the earth: for turning on its axis from west to east, the heavenly bodies must appear as turning from the east towards the west. We have proved that the

air is held fast to the earth by the power of gravity; and it must therefore revolve with it; so that if the medium in which we live be carried along with us, it will be impossible for us to perceive the earth's motion, except by means of distant objects: and hence a bird is as effectually carried forward when on the wing as when at rest.

Besides this diurnal motion, the earth has another, called its annual motion, which is a journey it performs round the sun in 365 days 5 hours 48 minutes and 45 seconds. In this journey the seasons are produced by a contrivance, as the poet justly esteems it,

"Sublimely simple."

This was by inclining the earth's axis $23\frac{1}{2}$ degrees from a perpendicular to the plane of its road, or the ecliptic, as it is called: and by that axis continuing parallel to itself during this annual journey. By this beautiful contrivance the northern and southern hemispheres are brought alternately under the sun, and his blessings in a great measure equally distributed over the face of the whole earth. This parallelism will be easily understood by inspecting Fig. 7, where the line *n s* is the position of the earth's axis for every month in the year. The earth being divided into two hemispheres by its equator, *a b*, the northern one is addressed to the sun in the month of June, and, of course, that half of the earth is in the enjoyment of summer, the other half is in winter. In December, just the contrary takes place: the southern hemisphere becomes addressed to the sun, and is in summer; while the northern is turned from the sun, and consequently is in winter. At the equinoxes, in March and September, the sun is over the equator, and shines to the north pole *n*, and to the south pole *s*: as these centres, therefore, are in the boundary between day and night, every circle on the globe will be cut equally

by this boundary; and every spot on the earth will describe one-half of its diurnal revolution in the day, and the other half in night, and hence their equality at those times of the year. In April the sun will shine a little over the north pole, as may be seen in the Fig. 7; the day-part of the circle will be thus increased, and the night-part of it diminished. In May, he shines more over the north pole, and the days increase in length; but in June he shines $23\frac{1}{2}$ degrees over the north pole, so that all places within that distance of the pole have perpetual day; and the day-part of every place in the northern hemisphere, besides, has its longeſt days, as may be seen by a mere inspection of the figure. In July, he does not shine so far over the pole; in August less; and in September, he again shines no farther than to both poles, and equality of day and night again takes place. The earth's axis still keeping nearly parallel to the line in which it set out, the north pole now sinks into the dark half of the earth, and will not be in sight of the sun again for half a year, i. e. till the spring equinox: but so much as the sun in October shines short of the north pole, so much it will now shine over the south pole; in November more; and in December most of all, or $23\frac{1}{2}$ degrees: therefore it is now midsummer in the southern half of the globe, and midwinter to the northern half; as may be seen by an inspection of the figure. A spectator on the earth in March, sees the sun in a constellation of stars called Aries ♈. In April, in Taurus ♉. May, Gemini ♊. June, Cancer ♋, &c. So that the sun is usually said to pass through the twelve signs of the zodiac every year. The manner in which the sun enlightens the earth, the parallelism of its axis, and the increase of days and nights, may be naturally represented by a small terrestrial globe, hung by a string fastened to its north pole, Fig. 8. A circle of wire, *a b*, representing the plane of the earth's equator, may be held parallel to the table, and even with

a candle standing upon it. If the string be twisted a little towards the left hand, and the globe suspended even with the wire at *a*, the globe will begin to turn on its axis from west towards the east, and day and night will be strongly depicted on its surface by the candle. But if the globe be carried round the wire, to represent a year, the candle will illumine it to both poles, and every spot on its surface will describe half a circle in the enlightened part, and half in the dark part, and make equality of day and night through the year. This is, however, not the case in nature; for the plane of the equator inclines $23\frac{1}{2}$ degrees from the ecliptic, or plane of the earth's road round the sun: if then the wire be held with that inclination, as *a b c d*, and the globe be carried gently round it, the seasons, and increase of day and night, will appear as they are in nature; i. e. when the globe is at *a*, the candle enlightens it no farther northward than the arctic circle *n o*; all within which, in the middle of our winter, is deprived of a sight of the sun; while all places within the antarctic, or opposite circle, have perpetual day: at this time the candle shines vertically on the tropic of Capricorn. As the earth moves towards *b* (the vernal equinox), if a small patch be laid on latitude 50° north, it will shew how the days increase in England, and how the nights decrease. When it has arrived at *b*, the candle will then be perpendicularly over the equator; and, shining to both poles, equality of day and night will take place: as it proceeds towards *c* (the summer solstice), the days increase, and the candle shines more and more over the north pole; when it has arrived at *c*, the whole arctic circle, and the countries it includes, will revolve in continual sight of the sun; and all within the antarctic circle will be deprived of that sight. At this time the candle shines vertically on the tropic of Cancer. Moving from midsummer towards *d* (the autumnal equinox), the days will be found to decrease, and the nights to increase in length, till they come again to equality at *d*, and thence to the winter solstice, where we set out.

Though we say the inhabitants within the arctic and antarctic circles are at opposite times of the year deprived of the sight of the sun, they are not altogether deprived of his light; for the atmosphere reflecting and refracting the sun's light (see Optics), forms a twilight, that reaches 18° below the horizon, and which is represented by the light shade, Fig. 16, Optics. Hence the day breaks to us when the sun is still 18° below the eastern horizon, as at *c*; and we have his light in the evening till he sinks 18° below the western, as at *p*. But as the sun in summer rises considerably to the north of the east, and sets also to the north of the west with us, he both rises and sets so obliquely to the horizon, that twilight is much longer to the northern and southern parts than to those about the equator, where he rises and sets more perpendicularly. Hence, at midsummer Great Britain has no night; for even at twelve o'clock at night, the whole island is within 18° of the horizon, or boundary of the sun's light.

It might be asked, How we know that the earth makes an annual journey round the sun? Through the shaft of a deep mine, we can see the stars in the day as well as night: through a telescope, properly equipt and situated, we also can see them: of course we can see the sun and stars at the same time. Now if the sun be seen near a fixed star to day, he will be seen considerably to the east of it in a few weeks; and if the observations be continued through the year, we shall trace him round the heavens to the same fixed star where we began to make the observation: proving, that he must have made a journey round the earth in that time, or the earth round him. As these two bodies do mutually attract each other, and that in proportion to their quantities of matter, it follows, from the laws of motion, that the smaller body must make out by motion what it wants in matter, and of course the earth performs the journey. For if two balls of unequal size were fixed on the two ends of a wire,

Fig. 5, and thrown up, so as to turn round each other, a centre of gravity, *a*, would take place between them, round which they would move; the small one making out by its motion what it wanted in matter, and the large one making out by its matter what it wanted in motion: so the two circles, *b* and *c*, would be to one another exactly as the quantities of matter in the two balls.

It may also be asked, How we know that the earth's axis keeps always nearly parallel to itself? This is also matter of simple observation. Every one knows, that there is one star in the north which seems to be stationary, while all the rest seem to turn round it, as round a centre; this is called the polar star, and the earth's axis continually points towards it. Now if a circle turn round a centre, that centre may be conceived as without motion; so may the poles of our globe; and, of course, any body opposite to the north pole must appear to be stationary.

But it may be said, that the earth's axis does not point to the same part of the heavens at the two equinoxes, or the two solstices. For if *s* be the polar star, Fig. 5, No. 2, and the earth's axis at *a* point to it, surely, if that axis keep always parallel to itself, it does not point to that star when it is at the equinoxes, or at *b* and *c*. Here we have an opportunity of contemplating the immense distance of the fixed stars, when we see that the distance *b c*, or the diameter of the earth's orbit (nearly 200 millions of miles), is not capable of affording any angle, or parallax, that the eye can perceive; nay, that it is but barely perceptible, assisted by the nicest instruments! The star γ draconis, passes vertically over London nearly every twenty-four hours, and may be seen through a straight chimney in the day; but when viewed by the zenith sector, it is seen nearly in

the same part of the field of the telescope at the vernal as at the autumnal equinox; because the diameter of the earth's orbit bears so insignificant a proportion to the distance of the fixed stars.

Of the Celestial Globe.

This globe is intended to represent the face of the heavens, as the other is that of the earth. The eye must conceive itself in the centre of this globe, and looking towards its concave surface, as we look to the concave arch of the heavens. Thus situated, and the globe rectified, if a small hole was made through each star, the eye would see through that hole the very star in the heavens which that spot was made to represent: so exactly are the bearings and apparent distance of the fixed stars on the surface of this ideal concave represented on this globe! Astronomy is said to have originated with the Chaldeans and Egyptians, people famous for their hieroglyphics and allegories. The constellations, or figures, on this globe, are of this kind; and no doubt had a reference to the mysteries of their religion, and the operations and appearances of nature. The heavens were an eternal book, open to all mankind, and therefore fit to register ideas which they conceived to be most momentous. The Greeks were smitten with the grandeur of the conception; and crouded in several constellations that have an immediate reference to their fable. Modern astronomy has thought fit to continue these figures; as they afford an outline, or contour, that incloses, as it were, a portion of the heavens: and by using the Greek alphabet in each constellation, every star has a specific name that distinguishes it from all others; so that if a comet, or any strange appearance, occurred,

these figures would afford the means of pointing it out, even to a correspondent in China. The largest apparent star in each constellation has the first letter of the Greek alphabet placed near it; the second in magnitude the next, and so on. So Aldebaran would be called α Tauri; Arcturus, α Bootis; the star passing vertically over London, γ Draconis; and Pollux, β Geminorum, &c. Thus the stars may be spoken of as if each had a separate name. But many stars having been discovered since these names took place, and because a star, which had one letter appropriated to it, was found to have several smaller stars near it, this method has been further enlarged by adding the ordinal numbers, 1, 2, 3, &c. to these neighbouring stars, as may be seen in the monthly occurrences of the Nautical Almanack.

Astronomers also divide the heavens into three regions—the northern and southern hemispheres, and the zodiac. In the following table is contained the number of visible stars in each constellation, their magnitudes, and those selected for nautical observations.

Names of constellations, and the number of stars in each, according to Hevelius and Flamstead.

ANCIENT CONSTELLATIONS.

		Hevelius.	Flamstead.
Ursa Minor	Little Bear	12	24
Ursa Major	Great Bear	73	87
Draco	Dragon	40	80
Cepheus	Cepheus	51	35
Bootes		52	54
Corona Borealis	Nothern Crown	8	21
Hercules		45	113
Lyra	Harp	17	21
Cygnus	Swan	47	81
Cassiopeia	Lady in a Chair	37	55
Perseus		46	59
Auriga	Waggoner	40	66
Ophiuchus	Serpentarius	40	74
Serpens	Serpent	22	64
Sagitta	Arrow	5	18
Aquila	Eagle	23	71
Antinous		19	
Delphinus	Dolphin	14	18
Equulus	Horses-head	6	10
Pegasus	Flying-horse	38	89
Andromeda		47	66
Triangulum	Triangle	12	16
Aries	Ram	27	66
Taurus	Bull	51	141
Gemini	The Twins	38	85
Cancer	Crab	29	83
Leo	Lion	49	95
Coma Berenices	Berenices Hair	21	43
Virgo	Virgin	50	110
Libra	Scales	20	51
Scorpius	Scorpion	20	44
Sagittarius	Archer	22	69
Capricornus	Goat	29	51
Aquarius	Water-pourer	47	108
Pisces	Fishes	39	113
Cetus	Whale	45	97
Orion		62	78
Eridanus	River	27	84
Lepus	Hare	16	19
Canis Major	Great Dog	21	31
Canis Minor	Little Dog	13	14
Argo Navis	Ship	4	64
Hydra	Monster	31	60
Crater	Cup	10	31
Corvus	Crow	-	9
Centaurus	Centaur	-	35

Lepus	Wolf	24
Ara	Altar	9
Corona Australis	Southern Crown	12
Pisces Australis	Southern Fish	24

New southern constellations.

		Stars.
Columba Noachi	Noah's Dove	10
Robur Carolinum	Royal Oak	12
Grus	Crane	13
Phœnix		13
Indus	Indian	12
Pavo	Peacock	14
Apus, Avis Indica	Bird of Paradise	11
Apis Musca	Bee or Fly	4
Chamæleon		10
Triangulum Australis	South Triangle	5
Pisces Volans	Flying Fish	8
Xiphias	Sword Fish	6
Tourcan	American Goose	9
Hydrus	Water-snake	10

HEVELIUS's *constellations, made out of the unformed Stars.*

		Hevelius.	Flamstead.
Lynx		19	44
Leo Minor	Little Lion		53
Asterion and Chara	Greyhounds	23	25
Cerberus		4	
Vulpicula and Anser	Fox and Goose	27	35
Scutum Sobieski	Sobieski's Shield	7	
Lacerta	Lizard	10	16
Camelopardalis	Camelopard	32	58
Monoceros	Unicorn	19	31
Sextans	Sextant	11	41

Many other vacancies in the heavens have been filled up with scientific constellations, viz. an air-pump, a clock, a telescope, a microscope, a square, a compass, an easel, gravers, a chemical furnace, shop of the sculptor, &c. The cross is a conspicuous constellation, in the southern hemisphere. The bull of Poniatowski, and the sceptre of Brandenburg, are also new; but the stars in all

these have been enumerated in the old constellations, except those too far to the south, to be seen by northern observers.

The number and order of the stars, capable of being seen by the naked eye, are,

Of the 1st magnitude - -	17
2d - - - -	63
3d - - - -	196
4th - - - -	415
5th - - - -	348
6th - - - -	341
Unformed stars - - - -	326
	1706

There are nine conspicuous stars, near the ecliptic, and the moon's orbit, that are selected as proper stations to calculate the moon's distance from, both as she approaches towards them, and as she recedes from them; by which tables, in the Nautical Ephemeris, the longitude is found at sea. These stars are α Arietis, Alderbaran, Pollux, Regulus, Spica, Antares; α Aquilæ, Fomalhaut, and α Pegasi. These stars are so near the moon's path, that her distance from one or other of them is calculated for every three hours of time, for many years to come. Let *a b* represent the ecliptic, Fig. 59, Pl. 9, then may those nine stars be easily distinguished in the heavens, by their superior brightness, and their proportional distances and bearings, as in the Figure.

To the young astronomer, it must appear a little strange, why the zodiacal constellations and their symbols should not be together. The stars, for instance, that compose the ram, or Aries, are nearly 40° to the east of the first point of Aries, or where the equator cuts the plane of the ecliptic, marked ♈; and the bull about the same

distance from its symbol ♈; and so of the whole twelve signs, as they are called, of the zodiac. As the protuberance that surrounds the equatorial part of the earth, lies at all times obliquely to the sun's attraction, except at the equinoxes, that part will be liable to a more powerful attraction than any other part of the earth; by which the equatorial obliquity will be drawn more and more towards a level, at the rate of about half a second per year.

But I conceive the sun's attraction of the earth to be balanced by the repulsion of his light, at their medium distance; and, therefore, that the southern hemisphere, *s*, Fig. 11, will be more repelled at our winter solstice, than the northern hemisphere, *n*, at the summer solstice; as the earth, at that time, is above its medium distance from the sun, as in winter it is within it. Hence the unequal repulsion against the two hemispheres, and the tendency which the sun's attraction has to draw the equatorial protuberance out of its oblique state into a more parallel one, has altered the inclination of the earth's axis, so that it is one third of a degree more perpendicular to the plane of the ecliptic than it was in the days of Ptolemy: in his time it inclined 23° 48′ 45″ from that perpendicular; in our time 23° 27′ 56″. (See Lecture First.) Hence ♈ changes its place backward (or contrary to the order of the signs) 50″ every year, and the plane of the earth's equator crosses the ecliptic 20′ in time sooner every year: therefore, the equinoctial point ♈ goes back in the ecliptic one degree in 72 years, and occasions the disagreement of the zodiacal constellations, with the symbols that represent them. This makes a sensible difference in the latitude and longitude of the stars; and it becomes necessary to revise celestial globes and atlases every 72 years. The signs of the zodiac are symbolical of the seasons. The sun is seen in the Ram and Bull, in the fructifying season of spring. The crab is said to crawl back-

ward; and the sun begins to withdraw from us, when he passes through Cancer. He is seen in Leo, in the dog days; the fierceness of his rays is represented by a lion. Virgo has an ear of wheat in her hand, as an emblem of harvest: and the Balance beautifully represents the medium between the heat of summer, and cold of winter; of long and short days, &c. &c. Those signs are numbered in this singular way:

Aries	♈	0 sign.	Libra	♎	6th sign.
Taurus	♉	1st.	Scorpio	♏	7th.
Gemini	♊	2d.	Sagittarius	♐	8th.
Cancer	♋	3d.	Capricornus	♑	9th.
Leo	♌	4th.	Aquarius	♒	10th.
Virgo	♍	5th.	Pisces	♓	11th.

Each of these signs is divided into 30°, and each degree, into minutes and seconds: so that the situation of the sun, on the 10th of May, would be said to be in 1s. 20d. 0′, or 20th degree of the first sign.

The ecliptic being the path in which (referred to a fixed star) the earth travels through the heavens, it necessarily becomes the most important line on the celestial globe: longitude is counted upon it, from the first point of ♈; and latitude is counted from it, north or south. It is in the middle of a zone, or belt, of 16° wide, called the zodiac, and which includes the latitudes of all the planets: beyond this limit, north or south, the moon or any of the planets never move. The moon never departs from it further than 5° 20′, nor Mercury more than 7°. The ecliptic is crossed by four lines, at the four cardinal points of the heavens: those in the equinoctial points are called equinoctial colures; and those passing through the parts where the ecliptic touches the tropics, the solsticial colures. It is also crossed by meridians, which all meet at the two poles of the ecliptic. On these meridians is counted the latitude of the fixed stars, which

is their distance from the nearest part of the ecliptic; and what that part is distant from the first point of ♈, is called their longitude.

The *declination* of a star, is its distance from the celestial equator. The latitude, therefore, of Arcturus, is 31° north; its longitude 202°; and its declination 20° north.

The *right ascension* of the heavenly bodies is their distance from the first point of ♈, estimated in time on the equator. The earth turns 15° of a circle every hour, therefore the meridians are placed 15° from each other, for the easy counting of time; and hence the equator is divided into 24 hours. If a globe be made into a direct sphere, by bringing its poles into the horizon, and a star be brought to the eastern horizon, the place where the equator is cut by it will shew the right ascension in time. Thus the right ascension of Arcturus is fourteen hours and five minutes.

Oblique ascension of a star is an arc of the equator, reaching, according to the order of the signs, from ♈ to that point of the equator that rises with the star, in an oblique sphere: and the difference between the right and oblique ascension of a star is called its *ascensional difference.*

Time is measured by the apparent motion of the sun round the earth, and round the heavens; the time from his leaving any particular meridian, till his return to it again, is divided into 24 hours, and called a day; and the time from his leaving any fixed star, till his return to it again, is a year. The civil day is reckoned from midnight to midnight; but the astronomical day begins 12 hours later, and is from noon to noon, or the interval between two successive transits of the sun over the same meridian. This

day is not divided into two twelves, as the civil day; but goes on from one to twenty-four uninterruptedly; so that 18 hours of astronomical time would be 6 next day. But though the sun seems to go round the earth in 24 hours, the stars seem to go round it in 23^h 56′ 4″; so that they gain 3′ 56″ upon the sun every day, which amounts to one day in one year. This arises from the annual motion of the earth round the sun: which makes him appear to shift forward through the signs; nearly a degree every day; and therefore if a star was on the meridian with him to-day, I should find him nearly a degree to the east of it to-morrow, and my meridian would cross the star nearly four minutes sooner than it would cross the sun: the first of these is called a sidereal day; the latter, a solar day. Fig. 12 will render this familiar. S, is the sun: 1, is the earth, in a position where the sun and the star *d* would both crofs the meridian *a c* at the same time; but when the earth has arrived at position 2, it will be seen that the meridian, *a c*, will come to the star *d* sooner than to the sun, by the distance *o c*: when the earth comes to 3, the difference will be still greater; and when it arrives at 4, there will be a quarter of a circle difference, as from *o* to *c*, or a quarter of 24 hours, i. e. the star will cross the meridian fix hours before the sun. At this place, it may seem as if the plane of the meridian *a c* did not point to the star *d*: this arises from the immense distance of the fixed stars; in comparison of which, the whole diameter of the earth's orbit may be considered merely as a point. At 5, the distance *o c* continues to increase; and at 7, the star would be on the meridian 12 hours before the sun. This increase continues till the earth arrives at 1, where it set out; so that the sidereal year would contain one day more than the civil year. For if the sun and star were on the meridian at twelve o'clock, at No. 1, the star at No. 2, would cross it at ten; at No. 3, at eight; at No. 4, at six, &c. &c. &c. so it is found, that the

earth travels round the sun, from any fixed star, to that star again, in $365^d\ 6^h\ 9'\ 14.5''$. But this siderial year differs from the tropical year (on account of the precession of the equinoxes) $20'\ 29''$; for the time that the sun is in passing from either of the solsticial or equinoctial colures to the same point again, is $365^d\ 5^h\ 48'\ 45''\ 5'''$. The civil year, therefore, consisting of $365^d\ 6^h$, is nearly a medium between the sidereal and tropical years.

It is found, that a well-going clock and a sun-dial do not go together; but that the sun is sometimes faster than the clock, and sometimes slower. There are two causes to produce this effect: 1st, the obliquity of the equator to the plane of the ecliptic; and 2dly, the oval orbit of the earth, which makes it farther from the sun at one part of the year than another. Let ♈ ♋ ♎ & ♑, Fig. 13, represent the ecliptic; and ♈ ♎ the equator: and let us suppose the sun moving in the ecliptic from ♈ to *c*; while a star, or another sun moves from ♈ to *d*; and that the earth moved within this sphere of celestial meridians, *x* ♈ *z* ♎. Now, as the sun moves obliquely in the ecliptic, and the star directly in the equator, a meridian of the earth, *n m*, would cut the point *c*, before the point *d*; though they are equally distant from the point ♈, from whence the sun and star set out; so that, as the star represents the clock, it is evident the solar noon would be before that of the clock: at *d s* the obliquity would be still greater; but at ♋ ♑, the solstice, the quadrants coincide, the sun and star are in the meridian, and cut it at the same time. In the quadrant between ♋ and ♎, it is equally evident the meridian *t y* would come to the star *f* sooner than to the sun *t*; so that the clock would be before the sun from midsummer to the autumnal equinox, when they would again be together. From ♎ to ♑ the sun would be before the clock; and from ♑ to ♈ the clock before the sun.

These differences may be familiarly seen on a celestial globe; where, if a forefinger nail be placed 15° from ♈ on the ecliptic, and another 15° from ♈ on the equator, and the globe turned, that on the ecliptic will arrive at the meridian before the other, though their distances are the same. Any other two equal distances on the ecliptic and equator will meet the meridian exactly agreeable to what has been said on Fig. 13.

But the inequality of the sun and clock does not altogether arise from the obliquity of the ecliptic. The sun himself is not equal in his motion all the year. (Astronomers commonly speak of the sun as if he had motion; but it is the motion of the earth that should be understood.) The orbit of the earth is an ellipsis, and the sun may be considered as fixt in one of the foci of it. To make an ellipse mechanically, we stick two pins in a table, and tying the two ends of a thread together, lay it over the pins; then stretching it round them with a pen, or pencil, an ellipse will be made, and the place of the pins will be the foci; and S, Fig. 14, will thus be the centre of the sun. When the earth is at *a*, its nearest distance from the sun, the sun is then said to be in *perigee*; and when at *b*, its greatest distance, the sun is in *apogee*. Now, as it describes equal areas in equal times, and the space *c* S *d* is equal to the space *e* S *g*, it follows, that the earth will move from *c* to *d* in the same time it would move from *g* to *e* (when at its greatest distance, and partaking of the sun's attraction so much less). Let us suppose that it travels from *c* to *d* in one day; then would the meridian *m* describe the cycloid *m n* in that time. But the star *s* being on the meridian with the sun, when we set out from *c*, would become parallel, and point to *s* when it came into the direction *q r*; for *q r* is parallel to *m o*: therefore the earth must turn from *q*, the end of the sidereal day, to *n*, the end of the solar day, and the arch

q n would shew the difference of their lengths to be much greater than at the opposite time of the year. Call the distance *g e* one day's journey when the sun is in apogee, or middle of summer, and the star *x* on the meridian with the sun S; then would the meridian *z* describe in space the cycloid *z p* in one solar day: but that meridian would cut the star *x* before it came to *p*; for the meridian *w u* is parallel to *z x*. But here it must be observed, how much smaller the arch *u p* is than *n q*; and, of course, how much nearer solar and sidereal time approach to each other in summer than in winter. But if solar and sidereal time could be reduced to equal time, all the celestial motions, and all duration, would be reduced to one standard. This is an object of such importance in astronomical computations and observations, that it is calculated for every day through the year, and for many years to come, in every ephemeris of consequence in Europe. The theory of this reduction may be understood by the diagram, Fig. 15. A B C D represents the ecliptic orbit of the earth; or, which is the same thing, that, through which the sun seems to pass in one year. Therefore the earth is placed at E, and the sun in apogee at A, as he is a few days after he has passed the solstice at ♋. The ball, or star, *a*, is to be supposed moving round the circle in which it is placed with a perfectly equal motion. The sun and this star are at present together: but as the sun is in that part of the orbit where his motion is the slowest, the star will leave him, and arrive at *b*, at the time the sun is only at H. But as the sun's motion is now accelerated, he will overtake the star at C, and pass it before he arrives at K; for he is now in perigee, and moves so swift as to perform that half of his annual journey from ♎ to ♈ in eight days less time than the half from ♈ to ♎. Hence the reason why our summer half year is eight days longer than the winter half year. The conjugate, or

longer, diameter of the elliptic orbit A E C is called the line of the apsides*; and so far as the sun has departed from A, his apogee is called his mean *anomaly* (or *inequality* at any intermediate distance between the two points), whether it is at H, or B, or C, or D, &c. So if he was at *z*, 130° from his apogee at A, he would be said to be four signs and ten degrees from it, which is his mean anomaly; or if he was at *y*, 310° from the apogee, his mean anomaly would be set down as ten signs and ten degrees. Hence it appears, that when the sun's anomaly is less than six signs, the sun will be before the clock, which is represented by the equal-moving ball, or star, *a* and *b*: and when the sun's anomaly is more than six signs, the clock noon will precede the solar noon; and they will be together at the apogee A and perigee C. By the unequal motion of the sun, we find there are but two parts of the year in which the sun, and an equal time-keeper, can be together; but by the obliquity of the ecliptic, there were four times in the year when the sun and clock would be together: the real equation of time must, therefore, be compounded from these two causes of inequality: and what adds to the difficulty of the calculation is, that the line of apsides does not coincide with the line of the solstices; i. e. the apogee is nine degrees from it, viz. in the ninth degree of Cancer; and the perigee in the ninth degree of Capricorn.

The equation of time being calculated for every day in the year in the Nautical Almanack, and *Connoissance de Temps*; and placed also on the horizon of common globes for the second year after leap year; a table here would be superfluous.

* This diameter *conjoining* the aphelion and perihelion points in a line passing through ne centre of the orbit of a planet; to which the apogee and perigee correspond between the sun and the earth.

Reason of the Bissextile or Leap-year.

It is natural to suppose, that in the early ages of the world the length of the year must be very imperfectly laid down: the first attempt, that had any pretensions to accuracy, was made by Julius Cæsar, who fixed its length at $365^d\ 6^h$: this was too much: for as the real time that the sun goes from a tropic to that tropic again is $365^d\ 5^h\ 48'\ 45''$, there would be $11'\ 15''$ overplus every year. In 1800 years this amounted to eleven days, which, in England, was taken out of the month of September, in the year 1752. A similar reform had taken place in most parts of Europe, under the auspices of pope Gregory, in the year 1582. Our civil year of $365^d\ 6^h$ is still wrong; but, for the sake of easy reckoning, we call it no more than 365 days; and letting the six hours accumulate for four years, add one day at that time to the end of February, which brings all tolerably straight again. Suppose the earth touched the tropic at *a*, Fig. 16, and the year begun at that time; and suppose that in 365 days the earth had come short of the place where it set out, and got no farther than *b*: at *b* the next year commences: but the earth cannot get round its orbit to *b* again in 365 days; suppose no further than *c*. At *c*, then, the next year commences, and will end at *d*. Is it not evident, by such reckoning, we should, in time, have snow in June, and roses at Christmas? But the six hours so lost every year, in four years amount to a day; which, being added to the end of February, bring *d* back to *a*, and the year commences pretty near its right place.

END OF THE FIRST LECTURE ON ASTRONOMY.

LECTURE XI.

ON THE MOON.

As the moon is our own particular satellite, we are more interested in the knowledge of her character and properties, than of any other of the heavenly bodies, except the sun and our own planet. We do not consider this luminary as a primary planet; she is a mere satellite, or an attendant on the earth; shining by no light of her own, but borrowing her light from the sun, she reflects a portion of it to us, as any polished body would the light of a candle. Not that she is a polished body, for with the most ordinary telescope we can see her face covered with more inequality than our earth: long ranges of mountains, and numberless round pits that look like the craters of extinguished volcanos. With the naked eye we can see dark and light shades upon her, and which, through a telescope, look like land and water; for land will reflect the light of the sun much more than water; and the aeronauts, when high in our atmosphere, observed that our sea appeared more black and dark than the land.

A body borrowing its light from another, can only be enlightened on one side at a time; therefore, as the moon revolves round our earth in about twenty-nine days and a half, she must shew us sometimes more, and sometimes less, of her light side in that journey; and hence the phases, or different appearances, she assumes in one lunation. Let S, Fig. 17, represent the sun; *m*, the moon; and E, the earth. In this situation the moon will have her dark side turned towards the earth; and, if she can be seen, she will appear of a faint greyish colour, and ill defined, as *a*. This situation is called the change of the moon. Proceeding towards *n*, she becomes a crescent, and is called the new moon; for a spectator, *u*, after seeing the sun set beneath the western horizon, *u w*, would see the moon a little above it; and peeping under her, as it were, would see a little slip of the enlightened side, as at *b*. Proceeding on her monthly journey eastward, we now see her at her first quarter, and an half moon, as she appears at *c*: for now she is almost at the meridian when the sun sets at *u w*. As frequently the moon rises and sets in the course of a single night, this might appear like a real motion. But no: it is the motion of the earth on its axis from west to east, that makes her appear to move from the east towards the west; her real motion is from the west towards the east (the same way the earth turns on its axis), so that if we see her near any particular fixed star to-night, we shall see her thirteen degrees to the east of that star the next night, and so on. A few days after her first quarter, we shall find her at *p*: the spectator at *u* now looks at her almost in the same direction as the sun, when he sets; and, therefore, sees the greatest part of her enlightened face gibbous, or unequally projecting in approaching to circular. Almost fifteen days after her change, we find her at the full at *q*: now when the sun sets in the west at *w*, she rises in the east at *e*, and has performed half of her monthly circuit round the earth. A few

days after this she arrives at *r*, and becomes gibbous again, diminishing from her circle; for now a portion of her dark side appears opposite the sun: and at *s* she is again an half moon, and is said to be at her third quarter. In this situation, when the sun sets, she is on the other side of the earth to the spectator *u*; so that the earth must turn from *u* to *x* before the spectator can see the moon rise, which will be about twelve, or one, in the morning. When she arrives at *t*, a considerable portion of her dark side is turned towards the earth, and but a small part of her enlightened side can be seen, as at *h*; for now she rises but a little before the sun, and is again a crescent, but with the thick part of it turned to the east, as it was to the west when she was a new moon. In a few days after this, she again meets the orient sun, and disappears.

This is her ordinary monthly appearance, which may be naturally imitated by walking round a white ball when the sun shines upon it; those phases will then appear on the ball, as in nature.

Lunar Eclipses.

If the moon moved round the earth, on a level with the ecliptic, or, in other words, in the plane of the earth's road round the sun, she would eclipse the sun every time she came to the change; and be herself eclipsed every time she came to the full: for an eclipse of the sun is occasioned by the dark body of the moon passing between the earth and the sun; and a lunar eclipse by the moon passing through the shadow of the earth, and thereby losing her borrowed light. But the moon moves in an orbit that is oblique to that of the earth; one half of it being on the north side of the ecliptic, and

the other on the south: so that it crosses the earth's road in two points, which are called her nodes, making with it an angle of 5° 18′: see Fig. 18; where *n m* is the ecliptic, and *c d* the moon's orbit; *a* the ascending node (generally marked ☊), where she rises to the north, and *b* the descending node (generally marked ☋), where she passes to the south, of the ecliptic.

Now, though this orbit is a trackless path, that has no more substantial existence than the circle I make in the air with my hand, it performs a regular circuit round the zodiac retrograde, or contrary to the order of the signs, every eighteen years and 225 days; i. e. the node, or intersection, *a*, will in a year be removed to *e*, and the opposite node to *f*. In another year the ascending node will have gone back to *z*, while the descending node will cut *y*, &c. Hence when the moon is in the upper part of her orbit, *c*, she would be seen from the earth above the sun; and when in the lower part, *d*, below him: so that an eclipse could not happen but when the nodes lie in a line, or nearly so, with the sun and earth; as *a b*, Fig. 19. This figure represents both a solar and a lunar eclipse: at *c* the moon eclipses the sun; and a spectator on the earth at *e* would, for a few minutes, have the whole disk of the sun covered by the moon. For though the moon is a point in comparison of the sun, her nearness to us makes her commonly subtend as great an angle in the eye; and she, therefore, appears as large. But as her orbit is an ellipse, as well as that of the earth, and as its line of apsides is continually going forward in the order of the signs, so as to make a circuit round the zodiac in nine years, she sometimes eclipses the sun when she is in apogee, and sometimes in perigee. She is in the latter situation at *c*, where her central shadow reaches the earth: but was she in apogee, and farther from the earth, her central shadow would not reach it; her disk would appear less than that of

the sun, and, of course, a ring of his light would, to the spectator at *e*, appear round the dark body of the moon, and the eclipse would be called annular, from being like a ring. It is evident that the shadow of the moon on the earth would cover but a small part of it, so that solar eclipses are very local, and short in duration: for the shadow passes like that of a cloud over the earth at the rate of 2000 miles an hour: but lunar eclipses may be seen by a whole hemisphere at once.

Frequently a fortnight after a solar eclipse, we have a lunar one, if the line of the nodes, *a b*, be not removed out of the earth's shadow in that time. The moon first dips into the penumbral shadow at *z*, and continues very visible, till she arrives at the central shadow, when she assumes a copper colour, and is almost invisible; she then enters the other side of the penumbral shadow, and makes her exit at *n*, being about three hours in the whole passage. It might be supposed when she was in the middle of the shadow, and divested of her borrowed light, she must be invisible. This is not the case; for the atmosphere will refract, or bend, the rays that pass through it, at *r* and *q*, so much into the earth's shadow, as to throw a few on the moon in the direction *r f* and *q f*, and render her still visible.

There is also a penumbra in a solar eclipse as well as the central shadow, represented by the light shade round the conical one, Fig. 20, which gives a striking proof how very large the sun is in comparison of the earth. The dark shade *n o* is the track made by the central shadow over the earth; so that after the shadow has passed from *n* to *q*, a spectator at *n* would see the moon leaving the sun along the spotted line *n m* (while the spectator at *q* would observe a total eclipse). If he was nearer the centre of the pe-

numbra, he would have more of the sun's face cut off by the moon. So that, the diameter of the sun (in every direction) is supposed to be divided into twelve digits, as may be seen by the line *z q*, and three digits are eclipsed to the spectator *n*, on the sun's disk; and if the eclipse ended at *q*, would be said to end 90′ from a line passing perpendicularly through the sun's centre. Solar eclipses begin and end well defined as to time; but the earth's shadow is so faint, it is difficult, even with a good telescope, to ascertain the time when an eclipse of the moon begins or ends.

When the moon at full is a little distant from the node, she may yet suffer a total eclipse; because the earth's shadow is so much more in diameter than she. Let *a b*, Fig. 21, be the plane of the ecliptic, in some part of which the earth's shadow will always be. Let a section of that shadow be *c d* and *e*; and let *r s* be a part of the moon's orbit. If the moon is full at *c*, she will pass through the upper part of the shadow, and be but partially eclipsed. But when she is full in the node, as at *d*, that node must be in the middle of the shadow, and she will pass directly through it, and be totally eclipsed. So when the shadow is beyond the node, as at *e*, and the moon is at full there, she will pass through the lower part of the shadow, and be only partially eclipsed. But when she is at full at *z*, she would steer clear of the shadow, and not be eclipsed at all. This shews the limits of eclipses to be only near the node; and, by observation, it is found that a solar eclipse cannot happen at a greater distance from the node than eighteen degrees; nor a lunar eclipse at a greater distance than twelve degrees. An eclipse of the moon always begins on her eastern side, and goes off on her western; that of the sun on the west, and ends on the east side.

As solar and lunar eclipses can only happen at the change and full of the moon; and as the nodes go backward at the rate of $19\frac{1}{2}°$ a year; which, together with the annual change in the moon's apsides, render the exact calculation of eclipses a difficult problem; yet a tolerable guess may be thus formed. The above $19\frac{1}{2}°$ answers pretty nearly to 19 days of the sun's motion; the half of which being taken from half a year (viz. $9\frac{1}{2}$ from $182\frac{1}{2}$ days), leaves 173 days, the time of the sun's conjunction with one node, to the time he will be in conjunction with the other. Now as degrees of the sun's motion answer nearly to days (for there are 360 degrees performed in 365 days), it is plain there must be an eclipse of the sun, whenever the moon changes within eighteen days before or after the sun's conjunction with either of the nodes: and that the moon must be eclipsed whenever she is full within twelve days before or after the sun's conjunction with either of the nodes. The place of the moon's nodes may be found in most almanacks, and thereby at what new and full moons there must be eclipses.

As the sun passes through each node but once in the year, it is evident we can but have two capital eclipses of the sun and moon in one year. In some years there are but two, and both of the sun: there have been six in one year, four of which were of the sun; but these are several of them partial and invisible.

We generally say that nineteen years is the great period of the moon, and that at the end of that time she comes into the same part of the heavens with the sun she was at the beginning of it; and from thence begins a restitution of all their eclipses. This is not strictly true. In making 223 revolutions the moon comes in conjunction with the sun, and the node from whence they set out: but

this takes place in 18 years, 11 days, 7 hours, and 43½ minutes; and, therefore, if that time be added to the mean time of any eclipse, we shall have the mean time of the return of that eclipse. So that any one in possession of a set of almanacks for nineteen years, may easily calculate the time of any future eclipse, allowing for the odd hours which, every four years, makes leap-year.

It is a curious fact, that the time from the middle to the end of an eclipse, is always longer than from the beginning to the middle. May not this be occasioned by the impulse of the earth's centrifugal light; which, co-operating with the sun's attraction, accelerates the approach to, and retards the departure from, the middle? And may not the irregularity of the moon's motion about the change, be also occasioned by the reaction of the earth's light against that of the sun, in conjunction with the disturbance she meets with there by the sun's attraction? And as one-half of her monthly period is performed on that side of the earth which has no light to throw off, must there not be a disparity in the attraction and repulsion, which I apprehend to be the cause of her motion; may not this produce her elliptic orbit, the recession of her nodes, and the revolution of her line of apsides?

During the moon's revolution, she always keeps the same side towards the earth; or rather, perhaps, towards the other focus of her orbit, as *a*, Fig. 22, for the meridian *c d* has a constant tendency towards the upper focus of the lunar orbit, by which she acquires a longitudinal libration. In her syzigies, or conjunctions, at *p* and *z*, the meridian *c d* is in a line with the earth and the focus *a*, and her full face is seen; but as she approaches *n*, a little portion of her face on the right disappears, and a new part appears upon the left, as *o u*; which is again lost as she approaches *z*. From *z* to *q*,

a new portion on her right appears, and an equal quantity disappears on her left. These are called her *librations in longitude.* But as her orbit inclines five degrees and three quarters from the plane of the ecliptic *r s*, she will be at *p* so much above the level of the earth's path, the ecliptic, that one may look farther under her than at *q*; and when she is in her perigee at *z*, she will be so much below the level of the ecliptic, that one may look over her: these additions to her usual face are called her *librations in latitude*, and they reach about seven degrees farther than her medium face, towards her other side, which we never see. A lunar globe has been lately published by Mr. Russell, that not only shews the librations in the most perfect manner; but is a complete transcript of the mountains, pits, and shades on her disk.

When the moon rises at the full, in the east, she looks much larger than when she culminates, or comes to the meridian, and is, therefore, called the horizontal moon. This seems strange, when we reflect that the moon is considerably nearer to us when at the meridian than when in the horizon. Suppose a spectator at *a*, Fig. 23, sees her in the horizon at B, he will see her under an angle *c a b*; because her ray from her upper limb *d o* will be so refracted by the earth's atmosphere at *o*, as to be bent into the direction *o a*; and as we see every thing along that line in which the rays come to us last, we see the upper limb of the moon *d* along the line *a c*, and, of course, greatly magnified. But when she arrives more in the zenith, or at the meridian A, the rays are not so much refracted (see Optics) as when they fall more obliquely on the atmosphere; therefore she appears near her natural size. The moisture and vapours generally over an island contribute to this deception. Children believe every thing larger than it is, when looked at through a fog; and only from experience learn to judge right: our

want of experience in looking at the heavenly bodies makes us children, till by using micrometers, we learn to see the moon the same size in the horizon as at the meridian.

During our winter, the sun being in the southern part of the ecliptic, the full moons happen in the northern hemisphere; and (during what we call the light of the moon) shine upon the inhabitants within the arctic circle every second fortnight without setting, as may be seen upon any common globe; so that though they are deprived of the sight of the sun, they have so much twilight and moon-light, that their situation is not so forlorn as might be imagined.

Another, of what may be called the minor phænomena of the moon, is the harvest moon. She astonishes the ignorant by rising six or eight evenings near the same time in harvest, when she is about an hour later in her rising every day at other times. That she should be near an hour later in rising every other day, may be made evident by Fig. 24, where we will say the sun and moon are together on the meridian at twelve o'clock. Let the line *a c* represent a part of the earth's surface, and *d* the meridian of any place. Now in the time this meridian makes a revolution, and comes to twelve again, the moon will have travelled from 0 to 1, thirteen degrees (her mean motion) eastward, so that the meridian *d* will have nearly an hour to turn before it overtakes her. While the meridian makes another revolution, and comes again to twelve, the moon has travelled from 1 to 2, and the earth has to turn almost two hours before she is overtaken; for the earth turning fifteen degrees every hour, comes near the thirteen degrees which the moon travels every day; so that it is evident she must rise and set near an hour later every day, and, consequently, the tides (obeying her motions) will

observe the same intervals every day. But about the autumnal equinox she rises several days nearly about the same hour. This arises from the near approach to a parallel of the first part of her road through Pisces and Aries, with the horizon, of any high northern latitude. Let *a b* represent the horizon, Fig. 25, and *c d* the moon's orbit as it lies to the horizon when she passes through Pisces and Aries; and the small circles, the distance she travels every twenty-four hours. When that part of her orbit *c d* rises out of the horizon *a b*, in the direction *g f*, it must necessarily rise in a short space; therefore the seven days she is in going from *c* to *d*, she will be but a few minutes later in her rising every day than the preceding. But at the opposite time of the year, viz. in spring, her orbit lies a good deal in the direction *g f* to the horizon: then two of the round spots, that denote her daily travel, will cross the horizon in less time than the whole seven in the former situation. This may be made still more plain on a celestial globe: for if three patches are placed at thirteen degrees distance from each other, on the ecliptic, on each side of Aries, and the globe be rectified for London, or any higher latitude, they will be found to rise out of the horizon almost all at once; but if the same number be placed at the same distance about Libra, they will take up several hours. In this account we have treated the ecliptic as if it was the moon's path; for she deviating from it but five degrees and three quarters, it would make little difference. It may also be seen that we have twelve harvest moons in the year; for the moon passes through Pisces and Aries twelve times in the year; but at no time so convenient to be seen as at six o'clock in an harvest evening.

But of all the circumstances belonging to our moon, there is none in which we are so much interested as in that wonderful influence we find she has upon the waters of our seas, and the air

of our atmosphere: for that she affects both, there can be little doubt, when the tides in each element, keep such exact time with her motions. It may be thought, indeed, that we, who are destined to grovel at the bottom of our element, can know no more of what passes on, or near its surface, than those fish, which cannot rise from the bottom, can know of the tides on the surface of the sea. But we know that the barometer is more unsteady at the full and change of the moon than at other times; and that the sun and moon acting more in a line at the equinoxes than at other times, agitate the air and sea peculiarly at those periods. It is alſo said, that the full and change affect the nerves of the insane: all which indicate spring tides in the air, as well as the sea.

That the moon has an influence upon our earth, is certain from the nutation she causes in its axis. Suppose her in her greatest declination, and in perigee, Fig. 26, at *a*. It is evident she must have a stronger tendency to draw the earth's equatorial protuberance *d c* out of its inclination to the ecliptic, than when she acts upon it more in a line, as *c b*; and thereby to lift the axis out of its natural direction, i.e. into that of *z y*. This nutation was ascertained by Bradley, to alter the direction of the earth's poles 18″ in eighteen years and seven months, the great year of the moon. This influence being ascertained, its effects upon a flexible fluid may easily be conceived. Suppose the moon (soon after her change) hangs over the sea, as Fig. 27; that by her attraction in the line *a b*, she diminishes the gravity, or tendency which the sea has towards the earth's centre, and causes it to swell into the protuberance *c z d*: this protuberance cannot be stationary; as both the earth and moon are in continual motion; for the earth turning on its axis from west to east, under the moon, the protuberance will follow her from east to west (like a prodigious wave) over the great Atlantic and Pacific

oceans; and being thrown on the shores, will cause *flood-tide*, as it is called. It might appear hence, that the waters would be dragged from the European and African coasts, to the American; and by reverberating back again to them, cause a greater length of time between high-water and the moon passing the meridian. Certainly the moon passes the meridian before it is high-water any where; for water cannot be put in motion at once; nor can the tides get over sand-banks, and up creeks and rivers, until several hours after the moon has passed the meridian. Hence, it is not high-water at London until three hours after she has crossed the meridian. But as the moon hangs principally over the torrid zone, the protuberance under her must occasion a vacancy towards the north and southern zones; and hence the waters rush from the north and south towards the torrid zone, in both the Atlantic and Pacific oceans. This protuberance, however, cannot be perceived by a ship in sailing in those vast oceans; it is too extensive; it is only on the shores, and in creeks and harbours, that it is visible. When the sun and moon are in conjunction and opposition, the tides rise to a more than ordinary height, and they are called spring-tides. For the sun has an influence upon the sea, as well as the moon; but inconsiderable, from his immense distance: for as the power of attraction diminishes, as the squares of the distances increase, the sun's influence is considered only as three, while that of the moon is as ten. At the change of the moon, these two powers are drawing the same way, and, of course, thirteen may be said to be attracting the waters; and produce a spring-tide. But let us suppose a globe entirely covered with water, Fig. 28. It is evident the moon's greatest influence would be at *a*, where the water would be highest; and that it would become less and less towards *b* and *c*, and, of course, low-water at *d* and *e*. Now, let us suppose the moon at change, Fig. 29, where the sun is drawing in the same line; and the power

of thirteen is operating upon the waters of the sea; in this case, the water will rise to a more than ordinary height, and be a spring-tide, agreeable to experience. But when the moon comes to her first quarter at *d*, her influence will be in the direction *d c*, while the sun's will remain in the direction S *c*: the two powers will in a degree counteract the influence of each other; for the power of ten will act in the direction *c d*, while the power of three only will act in the line *c* S; and hence, at the quarters, neap-tides take place. When the moon comes to the full at *z*, spring-tides again take place. How is this? Are they not now better situated to counteract each other than at the quarters? Here we must premise (what every one knows), that we have two tides in little more than twenty-four hours; i. e. if it be high-water with me at twelve to day, situated at *n*, it will certainly be high-water with me soon after twelve at night, when I should be at the protuberance *m*: for wherever it it high-water, it is so, at the same time, to the antipodes of that place. That the sun and moon's united influence should be less at *m* than at *n*, there can be little doubt: but still the place *m* tends to the earth's centre *c*, as much as any other part of the globe, and is rather increased than diminished by the two powers which are drawing in the same direction. How, therefore, the tide *m* should rise for want of attraction, or from being left behind, at that place, I cannot conceive, though it is agreeable to the Newtonian hypothesis. A spectator at the sun, looking towards the earth and moon, would see them pass from his right towards his left hand, as in the Fig. 30, from A to B, which we will make to represent one lunation: the proportions being in the drawing pretty near what they are in nature; i. e. if the sun be supposed in the centre of the circle of which A B is an arch, then is *a o* the proportional distance of the earth and moon when she is at the change; the distances 1, 2, 3, &c. the distances

the earth travels in one day; and *a b c*, &c. the distance the moon travels in one day. Then may it be observed how a spectator at the sun would see the moon fall every day behind the earth till she came to her first quarter at *c*; how she approached to, and passed the earth at the full; how she went before him from the full to the third quarter; and then how the earth approached and overtook her at the change. For it is plain, when the earth is at 3, and the moon at *d*, she would be seen behind the earth; and when she was at *v*, and the earth at 20, she would be seen before the earth, &c. It may also be seen by this proportional drawing, that her track through the heavens is always concave to the sun, as well as that of the earth; that in every revolution she moves in one part faster, and in another slower than the earth; and that she goes from change to change in twenty-nine days and a half. But the drawing is made as if the earth moved round the sun in a circle; but its orbit is an ellipse; and there is much reason to believe, that it is not the earth that describes that ellipse, but the centre of gravity, between the earth and the moon, that describes it. For, as the earth and moon mutually attract each other in proportion to their quantity of matter; and as the earth's quantity is calculated to be forty times that of the moon, if her distance, 240,000 miles, be divided by forty it will give 6000 miles as the medium distance of the centre of gravity from the earth's centre. This agitation deviates but little from the track of the earth: and an idea of it may be formed from Fig. 31, where A B represents a part of the earth's orbit; *a* the earth, *c* the moon, and *d* the centre of gravity between them: now, while the earth travels from *a* to *g*, the moon travels from *c* to *v*, and comes to her first quarter; while the earth travels from *g* to *h*, the moon goes from *v* to *n*, and is at the full, opposite the sun; as the earth goes from *h* to *i*, the moon goes from *n* to *o*, and is then at her third quarter; and while

the earth travels from *i* to *k*, the moon travels from *o* to *p*, and comes again to the change, &c. From this drawing, it might appear that the moon travelled much farther and faster in her second and third quarters than in her first and last; whereas, we find that she performs these parts of her orbit pretty nearly in the same time, and apparently with the same speed. In regard to space, she moves as in the drawing; but in relation to the earth, she moves as far in her first as in her second quarter, &c.

The parts of the earth that are, in this period, farthest from the moon, will have a swifter motion round the centre of gravity than the other parts; or rather, the side *c*, Fig. 32, will describe the large circle *m n*, while the side *a* will only describe the small circle *p q*, round the centre of gravity *o*. Now, as every thing in motion always endeavours to go forward in a straight line, the water *c*, having a tendency to fly off in the line *c r*, will in a degree overcome the power of gravity, and swell into a heap or protuberance, as represented in the figure, and occasion a tide opposite to that caused by the attraction of the moon; and account for the two tides which take place every twenty-four hours and fifty minutes. This centrifugal tendency may be well illustrated by swinging a tumbler full of water vertically round, when the water will not be shed though its mouth is downward.

At the change of the moon, the sun's influence is added to that of the moon, and the centre of gravity will, therefore, be removed farther from the earth than *a o*, and, of course, increase the centrifugal tendency of the tide *c*: hence, both the attracted and the centrifugal tide are spring-tides, at that time. But spring-tides take place at the full as well as the change of the moon. Now it has been premised, that if we had no moon, the sun would agitate the ocean in a small

degree, and make two tides every twenty-four hours, though upon a small scale; his influence (from his distance) being but as 3, while that of the moon is 10. The moon's centrifugal tide, along the arch *c d*, Fig. 33, being increased by the sun's attraction, will make the protuberance a spring-tide, and the sun's centrifugal tide, along the curve *b i*, will be reinforced by the moon's attraction, and make the protuberance *b* a spring-tide; so spring-tides take place at the full, as well as change of the moon.

When the earth's axis inclines towards the sun, as in summer, and the moon is new, the day tides, in the north, will be greatest, and night tides lowest: at the full, the reverse. Fig. 34, will render this plain: *a* is the tropic of cancer, over which the moon is vertical; the day-tide, therefore, at *a*, will be highest: but the tropic at *b*, in the night-tide, will evidently dip but a little into the swell, and, therefore, be lower: at the arctic circle, at *c*, it is also evident there will be but one tide in the twenty-four hours.

When the moon is vertical to the equator, about her change, the sun's influence and her's will coincide; and their joint influence raise the tides to a more than ordinary height: this happens about the time when the sun crosses the equator, in March and September, when equinoctial tides and storms are proverbial, see Fig. 34. But as the sun is nearer the earth in winter than in summer, and, of course, nearer in February and October than in March and September, these equinoctial tides generally happen a little after the autumnal equinox, and a little before the vernal.

The time of the tides does not always answer to the same distance of the moon from any meridian: for the sun's attraction, at her change, retards her motion, particularly when both are in a line with

the earth. It is principally this, that makes lunar calculations so difficult. Neither do they happen alike to places on the same meridian; for capes, sands, shoals, creeks, &c. retard their motion, and hence they happen at every hour from the moon's departure from a meridian until her return to it again. Tides also are not so much perceived in the open sea, as in bays and rivers; which having wide mouths, and growing narrower, the *vis inertiæ* of the water in motion is such as to make it rise, like a huge wave, many feet above the level of the sea whence it came.

It may be asked, why the tides rise so little among the islands of the West Indies (seldom more than twelve or fourteen inches), when these island are so much more under the influence of the moon, than countries where the tides rise thirty or forty feet? To this it must be answered, that as the Atlantic turns under the moon, from west to east, her influence on its water must be from east to west; this tide, like a prodigious wave, is stopt by America, and reverberates back as the moon passes over the Pacific ocean. But in the same direction that the moon drags the waters of the Atlantic, the trade winds constantly blow; and so great is the power of wind, that tides every where are made greater or less according as the wind is with them, or against them. Now the Gulph of Mexico is a cavity between North and South America, into which the winds and tides are perpetually pouring in water; so that the first tide that ever flowed into it, may be said to be kept up in it by this unremitting influx; and, of course, the tides cannot rise and fall as in places less in the way of these two causes. But water raised above the general level always endeavours to fall back to that level; the trade winds, in some measure, prevent this, by blowing perpetually from the eastward. As water, so accumulated, cannot return in the teeth of the trade winds, it wheels round the west end of Cuba, and meeting with the Bahama

Isles, is turned northward along the coast of America; forming that most remarkable stream, the strong current of the Gulph of Florida. To shew that this accumulation does take place in the Gulph of Mexico, a survey was made across the Isthmus of Darien, when the water on the Atlantic side was found to be fourteen feet higher than the water on the Pacific side. It also is not improbable, from the shape and situation of the West-India islands, that they are the remains of a continent; the lower lands being washed away by the above influxes, and their places now occupied by the Carribean sea.

On the outside of Great Britain and Ireland, the tides run naturally from the north *towards* the moon; but, between the islands, they run unnaturally from the south towards the north, *from* the moon. This is occasioned by the near approach of the north ends of the two islands, and the obstruction given the tides in flowing through the Hebrides; hence, as the southern separation of the two islands is much wider, it is a more convenient entrance for the tides, and the Irish sea experiences a tide flowing from the south.

At the naze of Norway there are no tides; for the efflux of water from the mouth of the Baltic meets the tide of the North sea at right angles, and confounds its rise and fall.

There is a perpetual influx of water through the straits of Gibraltar into the Mediterranean: but this is not a tide; the moon has nothing to do with it. The sandy soil and deserts on the south of this great sea, receive immense heat from the sun, and impart it to the winds that pass over them; and as heated menstruums will dissolve more than cold ones, a south wind causes so great an evaporation on the surface of this sea, as to sink its level below that of the Atlantic: the ocean, therefore, pours perpetually in at the straits to

restore that level. This evaporation is often so great, that the sails of ships are constantly kept wet by the half-dissolved dews just above the surface; and these winds (called Sirocco), when they reach Greece and Italy, are so hot, and full of vapour, that they unnerve, and distress every creature that cannot escape out of their way.

There are many apparent exceptions to this doctrine respecting the tides: the Mediterranean has but small tides; the Baltic none. In the Euxine and Caspian, they can scarcely be perceived. The moon's duration on the meridian of these smaller bodies of water, is too short to put them in motion: the *vis inertiæ* of water is not easily overcome: for if the moon's influence was suspended for a while, and the waters subsided into their beds, when the moon resumed her influence, it would be some time before even the oceans themselves could be brought into that regular vibration they have at present. Capes, headlands, shoals, rocks, the inequalities at the bottom of the sea, &c. all contribute to the irregularity; but these allowed for, the whole is reconcileable to the above theory.

Newtonian Doctrine, respecting the Laws of Planetary Motion.

1st law. *Every body, or portion of matter, would continue in its present state of rest or motion, if not disturbed by some external cause.* This is called the *vis inertiæ* of matter, or that tendency which all matter has to lie still when not moved by external impulse, and to go on when put into motion. If a body be laid in any place, there we are sure to find it, if nothing removes it: and if I throw a stone, it would go for ever in the same line, if the resistance of the air, the power of gravity, or some other cause, did not stop it.

2d law. *All motion, or change in motion, is proportional to the force that is the cause thereof:* i. e. if a certain force moves a body with certain velocity, a double force will double that velocity, &c. and if a body be actuated by two contrary forces, it will obey neither, but proceed in a direction compounded of both. Thus, if I throw a stone in the direction *a b*, Fig. 35, while the power of gravity pulls it in the direction *a c*, it will neither solely obey the power of gravity, nor my impulse, but go in the diagonal *a d*, compounded of both.

3d law. *Re-action is always equal and contrary to action.* Thus, if a man in a boat, pulls another boat of equal weight by a rope, they will approach each other with equal velocity, and meet in the middle of the way. So in rowing, swimming, and flying; the oar may be said to push the water one way, the water pushes the boat the contrary way. Thus a man swimming pushes the water one way, and the water drives him the contrary way. Birds beat the air backward with their wings; the air drives them forward. So it may be said, that when a hammer strikes an anvil, the anvil returns the stroke. If I strike a stone with my hand, the effect is the same as if the stone struck my hand, &c.

Though these simple laws appear self-evident, they are equally explanatory of celestial phænomena as of the appearances on the earth. For if we find that the moon and planets fall from a tangent projected to their orbits, as a bullet does, shot from a precipice; this is strong proof that they are actuated by the same laws (see Fig. 3, Mechanics), and that their orbits are occasioned by a compounded force, the projectile force tending to a straight line, while the power of gravity bends that line into an ellipse. But why into an ellipse? In the first place, let us suppose a round board, *a*, Fig. 36, put into a swift circular and horizontal motion, with a ball *c* upon it, and

pulled towards the centre *d*, by a string and a weight hanging under the board. This weight may represent the gravity which any planet has towards the central sun. When the ball *c* partakes of the motion of the board, it will fly farther and farther from the centre *d*, till its tendency to fly off in a straight line, ſhall be balanced by the weight beneath the board: its motion then will be perfectly circular; its centrifugal tendency being just a balance for the centripetal. Here then is a law by which one body may revolve round another without coming nearer, or receding farther from, its attracting centre. But early in the progress of astronomy, it was found, that the moon and planets moved swifter in some parts of their orbits than in others: and that their parallax was accordingly greater in those situations, in which they move fastest: from these observations, there was proof of their orbits being elliptical; and that there had been no particular adjustment in balancing the centrifugal to the centripetal forces, at their first creation: and the celebrated Kepler had discovered, that a two-fold power of projectile or centrifugal force, would balance a four-fold power of gravity at all distances from the attracting centre. Let us familiarize this by Fig. 37, and suppose a planet, *a*, projected in the line *a d*, with a power inferior to the power of gravity *a* S: then would the centripetal power so far prevail over the centrifugal, as to bring the planet down to *c*: but what should prevent its nearer and nearer approach, until, in the spiral *c e*, it fell to the sun? Here this wonderful law becomes conspicuous. At *c*, the planet being twice as near to the sun as at *a*, it has four times the gravity at *c* as at *a* (because the power of gravity diminishes as the squares of the distance increase); but in its descent from *a* to *c*, its velocity increases by coming nearer and nearer to the sun, so that at *c*, we will suppose it moves twice as fast as it did at *a*. Now all motion having a tendency to become rectilinear (i e. if

motion be given to a body in ever so crooked or oblique a way, it will always endeavour to fly off in a straight line), the velocity which the planet has acquired at *c*, is not in favour of the spiral line *c e*, but in that of the tangent *c g*. Now if the four-fold tendency *c* S can be balanced by the two-fold projectile force *c g*, we see how the planet can relieve itself from the strong influence of the sun at its perihelion, and ascend by *k* to its aphelion at *a*. This is proved by actual observation of the planetary motions; and easily made evident by the whirling table.

Let the pulley *a*, Fig. 38, be supposed to be turned by a large wheel, and along with it the weights *b*, and the ball *c*, sliding on the wire *w*. The four weights are over the centre of motion, and to be lifted by a string going over the pulley *b*, and under the pulley *i*, and fastened to the heavy ball *c*. Fig 39, is actuated by the same large wheel, but the pulley *s* being twice the diameter of the pulley *a*, this part of the machine will but move half as fast as the other. Now as the balls *c* and *o* are of the same weight, and at the same distance from the centres of motion, their momenta must be the same, if they had equal motions. But it has been affirmed, that a two-fold motion, or power of projectile force, will balance a four-fold tendency to the centre. If so, the double swiftness of the pulley *a*, should make the ball *c* lift the four equal weights *b*, at the same instant the projectile tendency of the ball *o* should lift the single weight *k*, and shew that a two-fold velocity will balance a four-fold power of gravity. This is exactly so; and if this proportion was destroyed, by adding or withdrawing a weight, the experiment would not succeed.

By this do we discover another rule, viz. that all the planets, as well as their satellites, *describe equal areas in equal times.* Suppoſe S

the sun, in Fig. 40, and *a* the planet at its perigee; the strong tendency it has to fly off in the direction *a b*, brings it in a given time to *c*; in the same time it moves from *c* to *d*; and in the same time from *d* to *e*, &c. But all the triangular spaces, 1, 2, 3, 4, &c. are equal to one another, and of equal area; so that if the planet carried a string with it, one end of which was fastened to the centre of the sun, the string would pass over equal spaces in equal times. Thus do we see why our summer half-year is eight days longer than our winter half-year, as is plain by the figure; and why, perhaps, there is so much more land in our northern hemisphere than in the southern, being more fit for inhabitants by the medium severities of its seasons: for the earth being nearest to the sun in our winter, the rigour of that season is meliorated; and being farthest from him in our summer, that season has also its heat moderated. In the south, the contrary takes place; that hemisphere is addressed to the sun in their summer (being our winter), when the earth in her orbit is nearest to the sun; accordingly it is found that, latitude for latitude, their summer is much hotter, and winter much colder than ours. This unequal distance is also found by measuring the sun's apparent diameter with a micrometer, when it will be found, that the sun appears 32″, about $\frac{1}{60}$ of his diameter, larger at midwinter than at midsummer.

The elliptic orbit of the moon is irregular, as her motion is much disturbed by the attraction of the sun: this is evident in the winter, when the sun is nearest to us; for then she is so retarded by him, that her periodical month is longer than in summer. By this attraction also is the acceleration of the place of her nodes brought about; and the greater and less angle her orbit makes with the ecliptic every revolution: from these circumstances, she cannot exactly describe equal areas in equal times.

Distances of the Planets.

The shape of the orbits of the planets, and laws of their motion in them, being thus ascertained, we must now try to find their distances. Though this is a process not quite within the sphere of popular information, yet, I trust, it may be made plain even to those who have not made mathematics a study. Suppose the distance of the moon were our first object, and that we had a sea horizon, and were situated so as to have the moon pass our zenith. Then let A be the earth, Fig. 41, and *a* the place of the observer, who must be supposed to have a quadrant, *b c*, by which he can note the moment the moon comes to the zenith. Now as the moon apparently passes from a meridian to that meridian again in twenty-four hours and forty-eight minutes, she will perform a quarter of that circuit, viz. from *d* to *e*, in a quarter of that time, or in six hours and twelve minutes. But the observer will find that she will set before the six hours and twelve minutes are expired, which he must note: for when she comes to his sensible horizon *a c g*, she sets to him. Now as the sensible horizon is parallel to the rational horizon *k e*, a diagonal *a e* will make the angle *c z* equal to *n*, its opposite angle. To find what the angle *c z* is, say, by the rule of three, if six hours and forty-eight minutes be required for a quarter of the moon's circuit, or 90°, viz. from *d e*; how many degrees of the 90 would she pass through in the time of her going from the zenith to the sensible horizon, or from *d* to *g*? This will give the degrees of the arch *d g*, which being taken from 90°, or the quadrant *d e*, will leave the quantiy of the arch *g e*, or the angle *c z*. Now as the angle *n* is equal to *c z*, we are in possession of a right-angled triangle, *a k e*, with a side and an angle known; for *a k*, the semi-diameter of our

globe, is 3960 miles: now it is the property of a right-angled triangle to have its sides proportional to the signs of its opposite angles; therefore, as the angle *n* is to its opposite side *a k*, so is the angle *o* to its opposite side *k e*, or the mean distance of the earth's centre from that of the moon, viz. 240000 miles. This parallax, or angle *n*, is on a medium about 57″. But the refraction which a setting sun or moon's rays suffers near the horizon (see Optics), makes a considerable difference. This method does well enough for finding the distance of the moon in, or near, the torrid zone: but the sun is so distant, that his parallax or angle *g a* S is too small to be measured to any certainty, by an horizontal parallax. Dr. Halley, therefore, recommended the transits of Venus, which were to happen in the years 1761 and 1769, as the most perfect phænomena for ascertaining the distance of the sun. But even, as to the moon, on looking in our Nautical Ephemeris, we find the moon's parallax altering in the course of one month from 54′ to 61′, the cause of which may be seen in Fig. 42. Let E be the earth, and *a* its centre; from that centre (if the earth was transparent) we should transfer the moon at *b* to *c* in the starry heavens; when she was at *e*, we should see her at *x*; and when she was at *g*, the eye at *a* would transfer her to *z*, &c. These are said to be the *true* places of the moon. Her *apparent* places, are those in the heavens where she is seen when viewed from any part of the earth's surface. So that a spectator at *u* would see her at *d*, when she was at *e*; and when she got to *g* he would see her at *p*, &c. &c. So that the angle *e a b* would be her parallax, equal to the angle *x e d*; and hence her parallax is evidently most when near the horizon; it is less between *p* and *z*; less still between *n* and *m*; and none at all at the zenith *s*. So that with the greater or less obliquity with which she is situated to an observer, the parallax is perpetually varying.

By the transits of Venus, almost the *whole* diameter of the earth formed a parallax, instead of the above semidiameter, by which a commensurate angle was procured in this way. Venus moves in her orbit in the direction *z n*, Fig. 43, and from the centre of the earth *c*, would be seen to move over the sun's disk from *s* to *v*; an observer, therefore, at *a*, would see the contact at *s*, at the same instant that one at *b* would see the planet at *u*; and one at *d* would see it at its egress at *v*, along the line *d* V *v*: this would be the case, was the earth at rest; but it is turning on its axis, in the direction *a b d*. Now if the planet sood still at V, while the earth turned from *a* to *d*, that time would be easily turned into the parallactic angle *a* V *d*, and might be treated like that of the moon: but the motion of Venus, as well as that of the earth, was to be taken into this calculation, as well as observations made in different latitudes: the result of all which was, that the sun's parallax was found to be but about 8″; but small as it is, 'tis an angle whose sides admit of calculation; and the sun's distance, by this means, was found to be about 96 millions of miles.

The sun's distance being thus found, the distance of the planets from him may be found either by their retrograde motions, or by the celebrated problem of Kepler, viz. that the squares of the periodical times of the planets, round the sun, are in proportion to the cubes of their distances from him. As the times, therefore, of the revolutions of the planets are well known, and as we know now the distance of the earth from the sun, how am I to find the distance of Mars from the sun? By knowing that he is 686 days 23 hours 30 minutes and 36 seconds, in going round his orbit. By the rule of three, it will be as the square of the periodic time of the earth's motion round the sun (i. e. 365 days 6 hours 9 minutes

12 seconds) is to the cube of its distance (i. e. the cube of 96 millions of miles), so is the square of Mars' periodic time (i. e. 686 days 23 hours 30 minutes 36 seconds) to the cube of his distance from the sun. The cube root being extracted from that number, represents the proportional distance of Mars from the sun.

The way of finding the distance of a planet from the sun, by its retrograde motion, and by knowing the earth's distance from the sun, is thus, Fig. 44. Let S be the sun, *e* the earth, and *m* the planet Mars, whose distance, from the sun, is the object of enquiry; and let *a b* and *c* represent an arch of the heavens. Now as the earth moves almost twice round the sun while Mars moves but once, every twenty-second month we pass by him, and he appears at that time to go backward; for when the earth is at *e*, Mars would be seen at *a*; but as the earth passes from *e* to *d*, Mars would have appeared to go retrograde from *a* to *c*, though, in reality, he was going the same way as the earth, viz. from *m* to *g*. The arch *a c* is found by observing the planet in its retrograde state, and that gives the angle *a m c*, which is equal to the angle *c m d*, half of which is the angle S *m c*: hence we come in possession of an angle, and its opposite side of the right-angled triangle S *m c*; for S *c* is the distance of the earth from the sun, and the angle *m* is found as above: so, as the angle *m* is to the sine S *c*, so is the angle *c* to the opposite side S *m*, or the distance of Mars from the sun.

This problem is performed as if Mars stood still at *m*, while the earth was moving from *c* to *d*; but, in reality, he is going forward to *g*, and would be seen from *d* at *b*. But since the quantity of Mars' motion, during the time of his retrogradation, may easily be found, it may be known how much the angle *a m c* is diminished,

and, consequently, what that retrograde motion would have been had he stood still at *m*.

This method is applicable to all the superior planets; and the distance of the inferior planets from the sun, may be found by a similar process. Let S be the sun, Fig. 45; *a* the planet Venus, at her greatest elongation (or that place where she appears the farthest distant from the sun); *b*, the earth; and *c d*, a portion of the starry heavens. The triangle *a b* S is a right one; and the angle *b* is easily taken with a quadrant: being, therefore, in possession of that angle, and the line *b* S (the earth's distance from the sun), the perpendicular (or Venus's distance from the sun) is found by plain trigonometry, as in the last problem.

The mean distance of each planet from the sun, being thus found, we double that distance, and it is the diameter of their orbit; and as the diameter of a circle is to its circumference nearly as 7 is to 22, their orbits and hourly motion may be easily calculated, viz.

	goes round the sun at the rate of	miles in an hour, at the distance from him of	million of miles.
That Mercury	110680		$37\frac{1}{3}$
Venus	80955		$69\frac{1}{2}$
Earth	68856		$146\frac{1}{4}$
Mars	55783		499
Jupiter	30193		$916\frac{1}{2}$
Saturn	22298		1832
Georgium Sidus	16411		

This astonishing distance and velocity may be expressed in numbers: but neither numbers nor diagrams can implant in the mind any distinct idea of those astonishing distances, or motions! (which are yet almost as nothing to other distances, and other velocity). By applying facts, and images, to which we have been accustomed to assist the mind, a faint conception may be formed of them. A cannon ball moves at the rate of eight miles in a minute: accord-

ing to this, it may be computed, that in flying from the sun it would require the following time to reach,

Mercury - - -	$8\frac{3}{4}$ years.
Venus - - -	$16\frac{1}{2}$
Earth - - -	$22\frac{3}{4}$
Mars - - -	$34\frac{1}{4}$
Jupiter - - -	$118\frac{1}{4}$
Saturn - - -	$217\frac{1}{4}$
Georgium planet - -	$435\frac{1}{2}$
The fixed stars -	7,600,000

If balls, placed on poles, were made to represent the sun, and planets,

Mercury should be -	28 yards from the sun.
Venus - - - -	52
Earth - - - -	79
Mars - - - -	109
Jupiter - - - -	273
Saturn - - - -	684
Georgium planet - -	1357

Moon $6\frac{1}{2}$ inches from the earth.

The size of these balls, to bear a proportion to the above distances, should be,

The Sun - - - -	2 feet diameter.
Mercury - - - -	$\frac{1}{12}$ inch.
Venus - - - -	$\frac{1}{7}$
Earth - - - -	$\frac{1}{5}$
Mars - - - -	$\frac{1}{15}$
Jupiter - - - -	$2\frac{3}{4}$
Saturn - - - -	$2\frac{1}{10}$
Georgium - - - -	1 inch

Another mode of expressing proportional distances from the sun.

4	7	10	15	52	95	120
☿	♀	⊖	♂	♃	♄	♅

The distances of the planets being known, their magnitudes are calculated by their apparent diameters, at those distances. The sun, when seen from opposite sides of the earth at the same moment, appears in the same place, because of his great distance, and the small comparative size of the earth. The moon (though apparently as large as the sun) appears, to two observers, at only a few leagues from one another, in different parts of the heavens, on account of her nearness, and great parallax, which is 430 times as great as the sun's; the distances of the heavenly bodies being inversely as the tangents of their horizontal parallaxes. And we have observed that spectators, on different parts of the earth, saw Venus on different parts of the sun's disk, at the same moment. From those distances, and the angle the planets subtend at those distances, their magnitudes are calculated with tolerable certainty. Their largest apparent diameters, as seen from the earth, are, the Sun 32′ 36″, Mercury 12″, Venus 57″, Mars 27″, Jupiter 40″, Saturn 18″, the ring of Saturn 42″, Georgium Sidus 4″. Their real diameters, proportional distances, sidereal revolutions, &c. are expressed in the following table.

	Diameters in English miles.	Proper distance from the sun.	Sidereal revolution.	Inclination of their orbits.
			d h m s	
Sun	893522			
Mercury	3261	38710	87 23 15 14	7° 0′ 0″
Venus	7699	72333	224 16 49 11	3 23 35
Earth	7920	100000	365 6 9 12	
Moon	2161		27 7 43 0	
Mars	5312	152369	686 23 30 36	1 51 0
Jupiter	90255	520279	4332 14 27 11	1 18 56
Saturn	80012	954072	10759 1 51 11	2 29 50
Herschel	34217	1008180	83 years, 157 days and 18 hours.	0 46 20

CHARACTER AND PROPERTIES OF THE PLANETS.

The Sun.

THIS vast globe is the first of the celestial bodies that attracts our notice. It is the fountain of light, heat, and fire; the great illuminator of the world! It is the centre of the planetary system, administering to the various worlds which compose it, light, heat, and vegetation. By his attraction and repulsion he retains the planets in their orbits. His magnitude, distance, and density, have been calculated; and so many of his attributes ascertained, that there remains little doubt of his being, as it were, the soul and actuating principle of the system; as well as a world susceptible of inhabitants. By spots on his face we can see that he turns round on his axis in twenty-five days and six hours from east to west. If the emission of light were the whole of his destination, we see no reason why that might not be performed by a body at rest, as well as by one in motion. It seems consistent with analogy, and the frugality of Nature, in never doing any thing in vain, that this motion is to throw off centrifugal light through the zodiac; and thereby to give annual and diurnal motion to the planets. (See Optics, &c.)

Those spots by which we estimate the time of the Sun's rotation on his axis, have been thought the smoke of volcanos; scum floating on an ocean of fluid matter; clouds; nay, the Sun himself has been considered as a globe of fire. But, by observing them with a due magnifying power in telescopes, they are found to be hollow, and may be seen distinctly when they arrive at the edge of the sun, where a small indentation will appear on that edge, as *a*, Fig. 46; and from the shade that is seen round each spot, there appears a

shelving slope into each pit. Now this appears as if in common we did not see the real sun, but only his atmosphere, which, perhaps, may be of fluid fire, surrounding his black body like an ocean; and in which there may be commotions that may temporarily lay part of his body bare, and account for the spot, its surrounding shade, and the slip that seems cut out of the sun's edge when the spot is disappearing. Or, perhaps, we may see the dark nucleus through a thin part of his fluid atmosphere, as we see the wick of a candle through its flame; or the opaque ore through the intense flame of a furnace. This makes the Sun more like the rest of the system than any other suggestion that has yet appeared, and pleads strongly in favour of his being inhabited. Nay, indeed, we may consider him as the only planet in the system, and that our earth and the other worlds are but his satellites! Glorious luminary! can we blame ignorance for making thee a god! What a body must he be, when the whole orbit of the moon could not contain him! when his attraction and influence reach even beyond the Georgium Sidus! His axis inclines eight degrees from a perpendicular to the plane of the ecliptic, by which his centrifugal light (flying off in the plane of his equator) rises a little above, and falls a little below, the level of the ecliptic: this light may be seen a little before the sun rises, about the time of the solstices, and is called the *zodiacal light:* we presume this stream of light to be the cause of annual and diurnal motion in all the planets, and of all their irregularities. (See Section 1st and 2d, Introductory Lecture.)

Mercury. ☿.

This small planet moves round the sun so near to his body, that it is seldom we see him; and when we do, it is for so short time,

and always in the twilight, that we can see no spots upon his face, and, consequently, know nothing of his diurnal motion, or length of his days and nights: but we can see that he performs an annual journey round the sun in eighty-seven days twenty-three hours and sixteen minutes; so we say, in round numbers, his year consists of eighty-eight of our days. When we do see him, he appears like a little half-moon, shewing that he borrows his light from the sun. His annual motion and borrowed light being thus ascertained, we doubt not of the other qualifications necessary to make him a fellow world with the rest of the system; and though his heat is calculated to be seven times as great as our's, no doubt his matter and inhabitants are adapted to it.

As the inclination of Mercury's orbit is seven degrees oblique to the ecliptic, he can be well observed only near our equator, and seldom in high latitudes: therefore, though he passes so swiftly round the sun, it is generally above or below him; but when he passes through his node at the time of his conjunction with the sun, we see him pass over the sun's disk like a little round black spot. This is called a transit of Mercury.

Mercury is said to be 3222 miles in diameter, as calculated from the size he appears to the earth, viz. twelve seconds; to be thirty-seven millions of miles from the sun; and to move at the rate of 110680 miles per hour: the sun to him would appear seven times as large as to us.

Venus. ♀.

This beautiful planet is distinguished in the firmament by her chaste brilliancy; her light being so white as to cause sensible

shadow, and so vivid that at her greatest elongations she is visible, in the fullest daylight, to the naked eye: her surface is so free from spots, that her diurnal motion is only guessed to be twenty-three hours and twenty-one minutes. Her orbit, like Mercury's, is within our's, and, therefore, we never see them opposite to the sun, and she circumscribes it in 224 days 16 hours and 49$\frac{1}{2}$ minutes, at the rate of 80955 miles per hour. Her distance from the sun is about seventy millions of miles, and her diameter 8244 miles, found by its subtending an angle from the earth of fifty-seven seconds. Her axis inclines seventy-five degrees from the axis of her orbit: and hence the reason why she has two summers and two winters at her equator; why her tropics are much nearer her poles than our's; why her seasons increase and decrease faster than our's; and why she has seldom her forenoon and afternoon both of a length. The sun, however, by passing so swiftly from one of her tropics to the other, gives the heated places time to cool, and this, no doubt, is wisely calculated for the good of her inhabitants.

This planet is sometimes a morning, and sometimes an evening star, as may be seen by Fig. 47, where S is the sun, E the earth, and *a b c d e f* the orbit of Venus, and the direction in which she revolves round the sun. When she is at *a*, she will be seen from the earth at *k*, a little to the east of the sun, or just above the western horizon, when the sun sets: when at *b*, she will be seen at *m*, a little higher, when the sun sets: when she gets to *c* (her greatest elongation), she will be seen at *n*, forty-seven degrees above the sun when he sets, and where she will seem stationary for a few days; because she is then coming towards the earth pretty nearly in a line. As she advances towards *d*, she will be seen to come nearer and nearer to the western horizon every evening when the sun sets;

and at *e* she will be invisible (her dark side being towards us), except we meet her in the node, when she would transit the sun's face like a little black spot. All this time she has been an evening star. She has now passed by the sun, and we see her at *s*, a little before the sun rises. When she gets to *t*, we see her at *u* considerably before the appearance of the sun. At *f* she comes to her greatest apparent distance from the sun to the west, and is then nearer and nearer to him every morning, at *g*, *h*, &c. till she again passes behind him between *s* and *k*. So far we have considered the earth as standing still at E: but it is passing forward towards *z*; and shews why Venus is longer a morning than she is an evening star. During this revolution, we sometimes see more, and sometimes less, of her enlightened side, like the moon. When at *a* we see almost a full Venus; at *b* she is gibbous; at *c* she is like a little half-moon; from *c* to *d* she grows more and more a crescent, and at *e* quite dark; at *s* we see the thick part of the crescent towards the east; and being now so near the sun, she is observed in the day, &c. &c. To the inhabitants of this planet the sun will appear twice as large as to us; and Mercury will be a morning and an evening star to them as Venus is to us. Her atmosphere has also been calculated as fifty miles in height, from a shade appearing about five seconds upon the sun's face, before the dark body of Venus seemed to touch his edge, at the time of her transit.

The Earth ⊖ *and Moon* ☽.

Having devoted a lecture to this third planet in the order of the system, and its satellite the moon, we pass by them here, and ascend to

Mars. ♂.

This planet is known in the heavens by a dusky-red appearance: and as the red part of light has only momentum enough to pierce through a gross or thick medium, and as a duskiness appears over those stars that he passes near, a gross atmosphere is supposed to occasion this appearance. When he is opposite to the sun, or when we see him near the meridian about midnight, he is much more brilliant than in another situation (being five times nearer to us than at the conjunction); a large spot is then distinctly seen on his face, by which his diurnal motion is ascertained to be in twenty-four hours thirty-nine minutes and twenty-two seconds. His year is nearly two of our's, being 686 days 23 hours 30¾ minutes. Hence we see an analogy between this planet and the earth, a little striking, in their diurnal motion being nearly the same; and in his orbit being nearer in the same plane with our's than any other, crossing it only at an angle of one degree fifty-one minutes. It is rather surprising that he should have no moon; as he is almost twice the distance from the sun that we are: perhaps the height and refractive power of his atmosphere may prolong the sun's light. To Mars the sun would appear one-third less in diameter than to us, being 144 millions of miles from him; and his apparent diameter at the earth being but 27″, his real diameter will be 4189 miles: our earth would appear a star to Mars, about the size that Venus appears to us; and never above 48 degrees from the sun. His figure, 49, is also oblate, the equatorial being to the polar diameter as 131 to 127.

Jupiter. 4.

The next of the superior planets is Jupiter; the largest in the system, being 90228 miles in diameter, though to the eye he appears not so large as Venus; nor does he subtend so large an angle at the earth as Venus, his being but 40″. This vast planet is five times as far from the sun as we are; and has, therefore, but a twenty-fifth part of the light, heat, or gravitation that we have. He turns on an axis, perpendicular to the plane of his orbit, in nine hours and fifty-six minutes; by which his days and nights are of an equal length, and never vary. He has, from the same cause, no variety of seasons: it being perpetual summer near his equator, and perpetual winter towards his poles. From the excessive swiftness of his rotation on his axis, his equatorial diameter has swelled so as to make him a much more oblate figure than the earth; by which it is thought his clouds and vapours are thrown more immediately up to his equator, and appear like streaks, or belts, round him: this is made probable from their frequent change in number and situation; when their number is most considerable, one or more dark spots frequently appear between the belts, and disappear as they do. The remarkable spot, by the motion of which Jupiter's rotation on his axis was determined, appeared in 1694, and was lost till the year 1708, when it re-appeared, on the same part of his face, and has been occasionally seen ever since. The spots and belts seen the 7th of April, 1792, with a seven-feet Newtonian telescope, are exactly represented Fig. 59. Some also suppose these belts to be seas, and that those variations are occasioned by tides differently affected, according to the positions of his moons.

This noble planet is splendidly accompanied; having four satellites, or moons, attending him on his journey round the sun, which he performs in 11 years 314 day ands 10 hours, at the distance of 499750000 miles from him. The periods of Jupiter's satellites are,

	D.	H.	M.	S.
1st satellite revolves in - - - -	1	18	27	34
2d - - - - - - -	3	13	13	42
3d - - - - - - -	7	3	42	36
4th - - - - - - -	16	16	32	9

These four moons perform their revolutions round him with such exactness, that could we make correct observation of them at sea, we should have no occasion for time-keepers, or offers of thousands for finding the longitude; the eclipses of Jupiter's satellites would develope that desideratum beyond the correctness of any time-keeper. But how? Were there a flash of lightning, or any other instantaneous phænomenon, to happen, so high above the earth, that half the globe could see it at once, the longitude of the place of each observer would be easily ascertained. By longitude is meant the distance east or west that one place lies from another. So if I saw the flash of lightning at twelve by my clock, at the instant another saw it at one, then does the latter lie fifteen degrees east of the former; because the earth turns fifteen degrees every hour upon its axis from west to east. If another saw the flash at ten which I saw at twelve, then is he two hours behind me, or twice fifteen degrees to the west of me. If another saw the flash at seven in the morning, when by my clock it was twelve, the person was five hours behind me, or five times fifteen degrees to the west of me, or seventy-five degrees. Now the eclipses of Jupiter's satellites afford those instants, when seen through a good telescope. Call S the sun, Fig. 48, E the earth, *a* the planet Jupiter, and *b* his first, or nearest, satellite, just dropping into the

shadow of Jupiter, and instantly losing its borrowed light. Now suppose a person in the woods of North America, wishful to ascertain the longitude of the place, or, in other words, how many degrees the meridian of Greenwich was from the meridian of the place where he was. We may suppose him possessed of the Nautical Ephemeris, in which the exact time of every eclipse of Jupiter's satellites is set down for the meridian of Greenwich, for many years beforehand. On the night he purposes to observe, he sees the first satellite *b* will be eclipsed at six in the morning to all who are on the meridian of Greenwich; but being so far to the westward, he determines to watch late at night; and at twelve o'clock he sees the eclipse take place along the line xii *b*, at the same instant the people of London see it along the line vi *b*. Now as the earth turns fifteen degrees upon its axis every hour, and as there is six hours difference, it is evident he lies six times fifteen, or ninety, degrees west of Greenwich, which would be the true longitude of the place to be put on a map or globe. The motion of a ship has hitherto prevented this simple method of finding the lontude at sea from being effectual; and hence the large premiums offered for a clock or watch that would keep time with the sun in all climates. The use of such an instrument would be to set it with the sun at the place whence a ship was to sail; as suppose the Land's End; the ship bound for Quebec. Now if the ship sails at twelve o'clock, due west, the observer will find next day at twelve his watch and the sun not together: by his quadrant he will find, perhaps, the sun on his meridian, when the watch is at one o'clock. It must be observed, that the watch keeps the time of the place he departed from; and, therefore, that place passing the sun sooner than the place where he is, will make a difference in the time pointed out by the sun and the watch. If an hour, as above, he is fifteen degrees to the west of the Land's End. The wind con-

tinues fair, and next day, when the sun is on his meridian, he finds it two o'clock by his Land's End watch; so that in two days' sailing, the clock and the sun differ two hours, or twice fifteen degrees, therefore he is now thirty degrees west of the Land's End. Thus a time-keeper that would go exactly with the sun, would make the art of finding our way upon a trackless ocean of no difficulty; for finding the latitude by the stars and the sun is made easy by tables. And thus, if we can know by observation, how far we are to the east, the west, the north, or south of the place we sail from, our track and situation can be marked on a chart, just as roads are upon a common land map. But heat and cold, moisture and dryness, imperfections of contrivance, and workmanship, all conspire to render this machine incorrect: so that we are still obliged to resort to celestial motion for finding the longitude. The moon, from the swiftness of her motion, is the best adapted for this important purpose. Her approach to, and recedence from, remarkable fixed stars, is, at present, our only exact means of finding how far we are east or west from the meridian of Greenwich, or any given place. The moon's distance from the sun, from α Arietis, from Aldebaran, from Pollux, Regulus, α Aquilæ, α Pegasi, &c. calculated for every three hours, gives the longitude in time; which (as above) is easily reduced to degrees, and, of course, to miles. For example: I hold my quadrant flat, or on a level with the moon and the star for observation; I find in the Nautical Almanac they will be distant from each other 75° at twelve this night: I watch with my quadrant and time-keeper, and at three in the morning, I find them just *that* distance. Why then it is evident, from what has been said, that I am three times 15° to the east of the meridian of Greenwich, or my longitude is 45° east. The manner in which these are placed in the Nautical Ephemeris is thus,

Distance of the Moon's centre from the Sun, and Stars east of her.

Stars' Names	Days	Noon	iii hours	vi hours	ix hours	Midnight	xv hours	xviii hrs.	xxi hours
		D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S.	D. M. S	D. M. S.
α Pegasi	17	67 13 19	65 45 12	64 0 32	62 16 22	60 32 43	58 49 37	57 7 7	55 25 14

As the astronomical day begins twelve hours later than the civil day, i. e. at twelve at noon, and is counted twenty-four in succession; we see in the above table that the star α Pegasi, on the 17th of June, will, at midnight, at Greenwich, be 60° 32′ 43″ east of the moon: at fifteen o'clock it will be 58° 49′ 37″ east of the moon, &c. Now if those distances are found by the sextant, at a time different from the table, the longitude of that place is also found. Suppose I see α Pegasi 62° 16′ 22″ at eleven at night, instead of nine, as in the table: then am I two hours to the east of Greenwich, or twice 15°, and my longitude is 30° east. Allowance, however, in this calculation must be made for refraction and parallax, agreeable to what has been formerly explained, which may be found in what is called the Requisite Tables, and other books of navigation. Though the cause of the refractive power of the atmosphere has been explained in the optical lecture, the ratio in which that refraction increases from the zenith to the horizon has not been stated. Here follows a table of the refractions which the light of the sun, moon, and stars suffers at different altitudes.

Appar. Alt.	Refraction.	Appar. Alt.	Refraction.	Appar. Alt.	Refraction.	Appar. Alt.	Refraction.
D. M.		D. M.		D. M.		D. M.	
0 0	33′ 45″	13 0	3′ 47″	39 0	1′ 6″	65 0	0′ 25″
0 15	30 24	14 0	3 31	40 0	1 4	66 0	0 24
0 30	27 35	15 0	3 17	41 0	1 2	67 0	0 23
0 45	25 11	16 0	3 4	42 0	1 0	68 0	0 22
1 0	23 7	17 0	2 53	43 0	0 58	69 0	0 21
1 15	21 20	18 0	2 43	44 0	0 56	70 0	0 20
1 30	19 46	19 0	2 34	45 0	0 54	71 0	0 19
1 45	18 22	20 0	2 26	46 0	0 52	72 0	0 18
2 0	17 8	21 0	2 18	47 0	0 50	73 0	0 17
2 30	15 2	22 0	2 11	48 0	0 48	74 0	0 16
3 0	13 20	23 0	2 5	49 0	0 47	75 0	0 15
3 30	11 57	24 0	1 59	50 0	0 45	76 0	0 14
4 0	10 48	25 0	1 54	51 0	0 44	77 0	0 13
4 30	9 50	26 0	1 49	52 0	0 42	78 0	0 12
5 0	9 2	27 0	1 44	53 0	0 40	79 0	0 11
5 30	8 21	28 0	1 40	54 0	0 39	80 0	0 10
6 0	7 45	29 0	1 36	55 0	0 38	81 0	0 9
6 30	7 14	30 0	1 30	56 0	0 36	82 0	0 8
7 0	6 47	31 0	1 28	57 0	0 35	83 0	0 7
7 30	6 22	32 0	1 25	58 0	0 34	84 0	0 6
8 0	6 0	33 0	1 22	59 0	0 32	85 0	0 5
8 30	5 40	34 0	1 19	60 0	0 31	86 0	0 4
9 0	5 22	35 0	1 16	61 0	0 30	87 0	0 3
9 30	5 6	36 0	1 13	62 0	0 28	88 0	0 2
10 0	4 52	37 0	1 11	63 0	0 27	89 0	0 1
11 0	4 27	38 0	1 8	64 0	0 26	90 0	0 0
12 0	4 5						

This estimate has its exceptions; for when the air is in a very dense state, its refractive powers are greater; and in a rarefied or lighter state, less. Moisture and rain increase its refractive power; and cold to a very great degree; insomuch, that some Hollanders, who wintered in Nova Zembla, and had a continual night of three months, found the sun appear to them seventeen days sooner than by computation he ought; which must have arisen from the sun's rays passing through the cold dense air of that climate. Why a

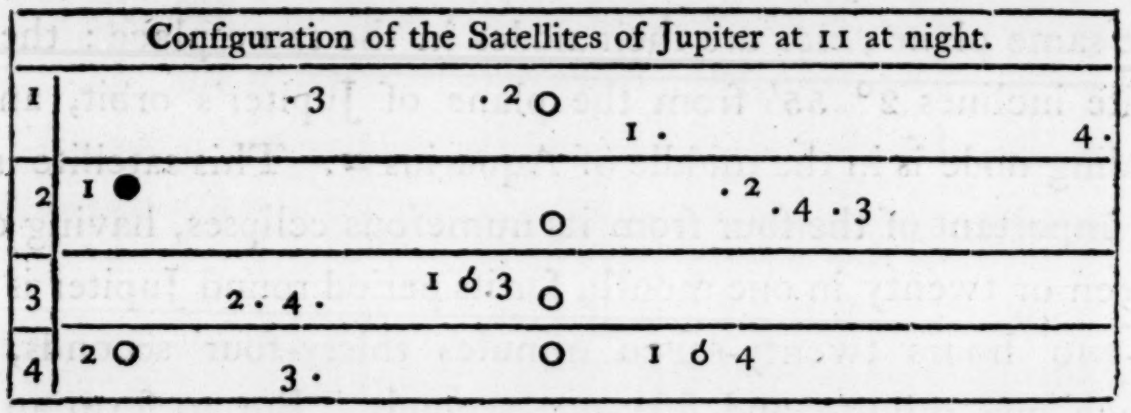
greater refraction takes place near the horizon than the zenith may be seen by Fig. 50, where E is a semi-earth, S the sun in the zenith to a person situated at *a*. The dark shade represents the earth's atmosphere, through which the ray S *a* passes perpendicularly, and without refraction (see Optics). But to a spectator at *c*, the sun would be seen at *i*, for the ray S *n* is bent at *n* into the direction *n c*; and as we see every thing along that line in which the rays from it came last, we see the sun along the line *c n i*. The observer at *g* sees the stationary sun S at *k*; for there the refracted ray *z g* is more bent: but the observer in the horizon at *s*, has the ray S *r* falling still more obliquely upon the atmosphere and bent in the direction *r s*; and hence he sees the sun S at *m*, under the greatest refraction.

But to return to Jupiter. His satellites do not revolve round him in the same plane; nor are their nodes in the same place: the first satellite inclines 2° 55′ from the plane of Jupiter's orbit, and its ascending node is in the middle of Aquarius ♒. This satellite is the most important of the four from its numerous eclipses, having often eighteen or twenty in one month, for its period round Jupiter is only forty-two hours twenty-seven minutes thirty-four seconds, and distance one minute and fifty-one seconds. But to form an idea of the track which all the satellites make through the heavens, as they accompany Jupiter on his annual journey, see Fig. 51, where the progress of sixteen days is depicted, and figures annexed. Let Jupiter be at *a*, and his four satellites in conjunction. Now while he travels from *a* to 1, his first satellite will travel to 1; and while Jupiter travels from 1 to 2 (his second day's journey), the first satellite travels from 1 to 2, having made a *loop* below the orbit of Jupiter; so that the configuration the first day after the conjunction would be as in the figure, viz. the first satellite would be seen on the left of Jupiter, and the other three on the right; for it must be sup-

posed we are looking at them on a level with the ecliptic; or as if we took the paper that contains the figure, and held its edge to the eye.

It is curious to observe in this figure, that the three first satellites come nearly into conjunction every seventh day: in that time, the first satellite has made four revolutions round the planet; the second satellite, two revolutions; and the third satellite, one. In the next seven days, it may be seen, the fourth satellite comes nearly to the weekly rendezvous; but he moves so wide as to be seldom eclipsed, or in conjunction. By this figure may be seen how Jupiter and his moons have their configuration in the Nautical Ephemeris: thus,

Configuration of the Satellites of Jupiter at 11 at night.



On the first of the month, at 11 at night, the 2d and 3d satellites are on the left of Jupiter; and the 1st and 4th on the right: it may be seen also, that there is obliquity in their orbits; that the 2d and 3d are in northern latitude, while the 1st and 4th are in southern latitude.

On the second day, at the same hour, the 1st satellite is in eclipse; and the 2d, 4th and 3d on the right of the planet. On the third day, at the same hour, the 2d and 4th are on the left of the planet, while the 1st and 3d are so much in a line or in conjunction that they appear but as one. On the fourth day, at the same hour, the

2d satellite would be seen like a bright spot on the disk of Jupiter; the 3d, on his left; and the 1st and 4th, in conjunction on his right.

The moons of Jupiter turn round him the same way he turns on his axis, in the order of the signs: so that when we see a satellite beyond Jupiter as it were, its motion is direct; as from *a* by *b* to *c*, Fig. 52. But when it moves from *c* by *d* to *a*, its motion appears retrograde: hence, they all seem to vibrate from one side of him to its opposite, some moving direct, and others retrograde.

Jupiter himself has one retrograde and two stationary appearances every thirteen months: for in that period we always pass by him. Let *a* represent Jupiter, Fig. 53, and *e* the earth: now while the earth is moving from *e* to *m*, Jupiter will appear stationary at *x*; but while the earth moves from *m* to *n*, the planet will have appeared to go backward from *x* to *z*; and while the earth moves from *n* to *q*, the planet will appear retrograde from *z* to *r*: but while the earth moves from *q* to *s*, Jupiter will again seem stationary at *r*. This is a strong and clear proof that the earth is not the centre round which the heavenly bodies revolve; for were that the case, the retrograde and stationary appearances of the planets had never existed. But if the earth be a planet among the rest, moving faster than the superior planets, and slower than the inferior, those appearances must take place; as it would be in two unequal sailing ships going the same way; to the swifter, the slower would appear to stand still or to go backward.

When we are in that part of our orbit nearest to Jupiter, we see the eclipses of his satellites sixteen minutes sooner than when in the remotest part; proving light to be progressive, and that its influence

comes from the sun to us in about eight minutes. This was first observed in those parts of the earth's orbit which lie in the same line with Jupiter, as *e* and *m*, Fig. 53. Now if the effect of light were instantaneous, an eclipse at Jupiter would happen at *e* at the same time as at *m*, but the most common observation will prove it is not so; but that the eclipse is seen several minutes sooner at *m* than it would be at *e*. Besides, the instant when any of these eclipses will happen is easily determined by calculation; because the times in which they perform their revolutions are known; and, therefore, if they take place sixteen minutes sooner when the earth is nearest to Jupiter than when it is in the farthest part of its orbit from him, it is evidently occasioned by the time which light takes up in being put in motion across the diameter of the earth's orbit.

With what inconceivable velocity must light impel light through such an amazing extent of space! ninety-five millions of miles in eight minutes! a million of times swifter than a cannon ball!—the mind shrinks from the pursuit of such an idea.

Even as to the fixed stars, it was long suspected that they were seen a little differently in their situations at one time, in our annual journey round the sun, than they were at another. Bradley observed in a zenith sector, or perpendicular telescope, the star γ Draconis in a different part of the field of the instrument at one part of the year than it was in another; and soon conceived that this appearance must arise from the progressive motion of light: which may be thus explained. Suppose *a b*, Fig. 54, a part of the earth's orbit, and that a spectator at *a* were observing the star *c*; and that the motion of light was to the motion of the earth as the line *c b* to *a b*; then by the time the earth had travelled from *a* to *e*, light

would have been impelled from *c* to *g*, and the star would be seen at 1. When the earth got to *i*, light would have fallen to *z*, and the star would be seen at 2; so that when the earth arrived at *b*, the star would be seen at *d*. Or suppose a drop of rain were to fall through the inclined tube *a b*, Fig. 55, it is evident, that if the tube were pushed from *b* to *c*, while the drop would fall from *a* to *c*, that the drop would fall through the tube without touching its sides. So it would be with a particle of light; that when the tube arrived at *c*, the particle would be seen at *d*. This is called the aberration of light; and proves that particles of light are streaming from every star in the heavens, and that the immensity of space is filled with moving light in all directions!

Jupiter's equatorial diameter is 6000 miles more than his polar diameter; or they are to each other as thirteen to twelve. His orbit is inclined to the ecliptic only 1° 20′. His aphelion (or place where he is farthest from the sun) is the 9° 10′ of Libra, and that is but $\frac{1}{20}$ of his mean distance from the sun. His ascending node is the 7° 29′ of Cancer; and descending node of course the same in Capricorn. This planet, seen from his nearest moon, would appear 1000 times as large as our moon does to us; increasing and waning like her, every forty-two hours. An observer from Jupiter would see two kinds of planets, four near him (i. e. his satellites), and two remote, viz. the Sun and Saturn; but the sun would appear but the 48th part so large to him as to us.

Saturn. ♄.

This stupendous planet deceives the eye, by its pale and feeble light; for, next to Jupiter, it is the largest in the system. It subtends an angle at a mean distance from our globe of 18″; and is

29 years, 167 days, and 6 hours in going round the sun. From these data, his diameter is calculated to be 79979 miles, and his distance from the sun 916,500,000 miles. His diurnal motion is not yet well ascertained; being so remote, and his spots are so ill defined; though it is said to be in ten hours and sixteen minutes. Five satellites were discovered many years ago; and lately two more have been added to the five; besides these, a large broad, double, and luminous ring surrounds his orb, which must add greatly to the light derived from his seven moons. This vast ring must appear to his inhabitants like a distant and immense arch of light in the heavens, and was probably intended to assist the imperfect light to which he is subjected by his distance from the sun. With these assistances, and the sun's original light, which is computed to be 500 times the light we have from our full moon; though his light and heat is so far inferior to ours, no doubt the eyes and constitution of his inhabitants are adapted to them; and that he may be as comfortable an abode as the worlds that are more enriched with those blessings. Saturn appears through a telescope of 400 magnifying power of the size and figure of Fig. 56. In this may be seen the shadow of the planet on the lower part of the double ring; and a spot between two belts. Sometimes he appears like Fig. 57, and of that size, seen through an ordinary telescope. This ring is calculated to be 204883 miles in diameter, surrounding Saturn at a distance equal to its breadth: it inclines about thirty degrees to the plane of the ecliptic; and by roughnesses on the edge, can be perceived to turn on an axis perpendicular to its plane, in eleven hours. With this inclination, it keeps parallel to itself, as Fig. 58, during the thirty years' revolution of Saturn round the sun. It is plain, therefore, that twice in this journey, viz. every fifteen years, the plane of this ring will be with its edge towards us; and then it will appear like a line over the body of the planet, reaching some dis-

tance on each side of it, as at *a* and *b*. If this ring be opaque, as the sun shines fifteen years on its north, and the same time on its south side, it will have equal day and night; each fifteen years long. This may be better understood by the Fig. 58.

The fifth satellite of Saturn evidently turns on its axis, as it varies in brightness in proportion as it advances in its orbit; and it is probable all the rest do the same: their periods round the planet are—

	d.	h.	m.	s.
1st satellite in - - -	1	21	18	27
2d - - - - - -	2	17	41	22
3d - - - - - -	4	12	25	12
4th - - - - - -	15	22	41	12
5th - - - - - -	79	7	47	0

The periods of the two late discovered satellites are,

6th - - - - - - - -	8	53	9	
7th - - - - - - - -	22	40	46	

The swiftness of Saturn's motion on his axis produces an oblate figure; so that his equatorial diameter is calculated to be to his polar diameter, as 11 is to 10.

Georgium Planet, or the Herschel.

This planet was discovered by Dr. Herschel, in March, 1781. From the slowness of its motion, astronomers had mistaken it for a fixed star: Flamstead made it the 34th star in Taurus; and the discoverer at first supposed it to be a comet. It was found nearly in a line with Castor and Pollux, and so near the ecliptic, as naturally suggested a suspicion of its being a planet. Its regular motion was soon discovered, which removed all doubts of its being a planet;

particularly when it was found to be accompanied with two satellites. Subsequent observations have added four more, two of which are said to move in a retrograde motion, or contrary to the order of the signs. It is calculated by M. de la Lande to be eighty-nine times larger than the earth; to be nineteen times further from the sun than the earth; and that its year is the length of eighty-two of ours. The apparent diameter of this planet being but four seconds, it can only be seen by the naked eye in the absence of the moon: it is of a bluish white colour, and well defined, when seen through a telescope of a considerable magnifying power.

The periods of its satellites are as follows:

	d.	h.	m.	
1st, or nearest, in	5	21	25	late discovery.
2d - -	8	18	0	discovered some time ago.
3rd - -	10	23	4	late discovery.
4th - -	13	12	0	discovered before.
5th - -	38	1	49	late discovery.
6th - -	107	16	40	ditto.

COMETS.

These seven primary planets, and the eighteen secondary ones, or moons, are considered as the regular bodies of the solar system: They move pretty nearly on the same level, and in the same direction. But the system is sometimes visited by other bodies, which approach the sun in all directions. These are called comets; from their having generally a stream, or hair-like appendage, adhering to them. The various opinions of the learned, respecting those wonderful bodies, would fill a volume. Halley conceived them to be planets, moving in very eccentric orbits, but describing equal areas in equal times, and therefore having their periods reducible to calculation. He contends for the comet of 1682, of 1607, of 1531, of 1456, and 1305, being one and the same; and that the difference in these periods was occasioned by the attraction

of Jupiter, as the path of the comet lay near him; but that it would appear again in the year 1758. A small comet was thought to be seen at that time, by a few observers in France, but so unlike the comet of 1682, in size and duration, that it was impossible to be conceived the same. We have been looking out for another these ten years, that should have appeared according to the above calculation, but it has not yet appeared. When we find such excellent astronomers and mathematicians, as Dr. Halley, mistaken, I fear we must suspect that the motion of comets does not come within the sphere of calculation. Sir Isaac Newton supposed the tails of comets a kind of vapoury atmosphere, rarified by the sun, and brushed behind the comet by his emanating rays (for the tail of a comet points always from the sun); and that this moisture might be intended to supply the waste, occasioned by vegetation, on the several planets; and, perhaps, at last, the comet might fall into the sun, and recruit him with fresh fuel. Others have supposed them capable of being inhabited, notwithstanding their extremes of heat and cold: that as they approach the sun the atmosphere becomes so rarefied, as to be incapable of imbibing or retaining heat; and that as they recede from him the atmosphere wraps more round them, becomes more dense, and of course more susceptible of imbibing heat. Observing that the tail of a comet, the aurora borealis, and electrical light, do not refract or bend light that passes through them, i. e. that stars seen through the tail of a comet, and through an aurora, are seen in the same place, as if there was no such matter between them and the observer; it has been supposed that these three phænomena are of one and the same kind of matter.

Hevelius supposes the nucleus, or head of a comet, to be transparent; and that the sun's light passing through it, forms the

tail. This idea is ingenious; and I see nothing in the numberless observations upon comets, that proves their nucleus opaque. May I hazard a conjecture in such learned company? Many comets have been traced to the sun, and have not been found to return from him: as many comets have been discovered retrograde as direct, in their motion towards the sun: and it is remarkable that (except the comet of 1744) they have all moved very oblique to the ecliptic; at great angles, as 36°, 48°, 88°, &c. &c. If concentrated electricity be capable of assuming the appearance of a ball of fire, as proved in the Lecture on that subject, and that electricity be but solar light, in a state of great purity, may not contending light, meeting in space from several suns, form such a condensation, as to make a ball of embodied light, like the electrical thunderbolt?—That this ball shall be transparent, and impelled from this meeting by that stream of light which is the strongest, and forced towards the next sun? See Plate 1st in the book, and Fig. 34, Plate 6th, of Astronomy.

We have already suggested that centrifugal light is thrown off from the equatorial part of our sun, and that its repellency is greatest there; therefore, the sun's attraction will be less impeded about his poles, and of course be greatest there. Light is attracted by all bodies, where a repellent power is not predominant on their surface; therefore light, either in a dilute or concentrated state, may be drawn into the body of the sun, about his poles, notwithstanding the atmospheric repellency of his equatorial parts. May not this account for the obliquity with which the comets move, respecting the ecliptic, and the sun's equator, and their universal tendency towards his poles? May not the obliquity with which they fall towards the sun, make them sometimes pass by him? and by passing into his equatorial stream be thrown off to a considerable distance, before the medium becomes dilute enough for the

nucleus to disperse? and thus the comets to have the appearance of a revolution? Is not the irregularity of their appearance favourable to this conjecture? and is it not probable that meteors themselves are but smaller assemblages of concentrated light, which soon melt in corruscations into the general mass? It may be objected, that light having passed through a transparent body would be less than the light which surrounds it, and therefore that it could not be seen. To this I oppose Fig. 34, Plate 6, where *m* is the concentrated ball of light, caused by the meeting of the streams *s m*, *t m*, &c.: now if the impulse *n m*, and *t m*, be predominant, the ball will be pushed towards *s*, so far, perhaps, as to come within the attraction of a neighbouring sun; towards which it will be accelerated, and increase in brightness; the sun's rays carrying off a portion of its condensed light, as it passes through it, and thereby increasing also the brightness of the tail. That light is liable to this kind of concentration, we see in many instances; it darts in this state from iron in a white heat, in impalpable balls, that burst with report and emanation. Balls of electrical light fly through a vacuum; and concentrated lightning frequently assumes the appearance of a ball, and has been seen to roll along the earth before it burst. This kind of ball has also been produced by the excitation of common electricity. This is but another conjecture added to the many already in being; and it has its difficulties in common with them. No doubt, comets are ordained for some wise and useful purpose, in the scheme of creation, though we have not yet had penetration enough to find it out.

On the Fixed Stars.

If from the space allotted for the solar system we launch out into that infinity of space that surrounds it on all sides, we may contemplate wonders truly worthy of their divine Author! Whoever conceives the fixed stars to be placed in a concave surface, and equally distant, as they appear to us, must have a limited idea of creation; for one star appears large, another little, because they are placed at immense distances from each other: it is our limited sight that makes them appear equi-distant; for it is not improbable that the smallest apparent star is as large as the brightest, and only appears so from its greater distance. By the naked eye we can but see about 500 stars at once; so that all we can see in both hemispheres, is not much above 1000. This appears extraordinary, because we suppose we see thousands at once; but this is a deception of our eyes, which running from one star to another multiplies them without end. Select a portion of the hemisphere, on a clear night, and count the stars it contains, and you will be amazed at the smallness of their number. From this we must not suppose their number really to be small; by telescopes 2000 was added to the 1000 seen by the nakedey e, so that some time since the catalogue of fixed stars was about 3000. But by the improvements made in that instrument by Dr. Herschel, and the unremitting use he has made of it (by sweeping the heavens), not less than 30,000 have been added to the former catalogue! Nay, were our glasses still better, no doubt we should discover more. Our telescopes have their limits, as well as our eyes, but the space we explore has no limits! Can any one suppose these bodies were only intended to give a faint twinkling light in the night season, when thousands cannot be seen by the unassisted eye? And when an additional moon would have been more

effectual for that purpose, than the whole host of heaven? This twinkling appearance, at first sight, distinguishes the fixed stars from the planets, which shine by a bright and steady lustre, something like a distant candle. The fixed stars are mere points to us, from their immense distance; and therefore the smallest mote in our atmosphere will temporarily cover them: these perpetually floating in the air, cause this tremulous appearance; particularly near the horizon, where the stars twinkle most, because we look through a greater portion of the atmosphere in looking horizontally than in looking upwards. Besides this, the rays that seem to issue from a luminous body that is near (as a candle), are the reflection of the smooth moist surface of the eye-lids, that touch one another when we wink. But that cannot be the case in looking at a star; for its impression on the retina is a mere point, and it will cause vibrations round that point, in proportion to the intensity of its light: the telescope magnifying this point, strips the star of those rays. Floating motes do not disturb the light of a planet, because of the largeness of their apparent surface.

By means of the zenith sector, Hook, Flamstead, and Bradley, observed for some time the transit of γ draconis over this perpendicular telescope; hoping that the diameter of the earth's orbit might make an angle or parallax with it: not at all! The star was seen so near the same place, when the earth was at its spring and autumnal equinox (near 200 millions of miles different), that no estimate could be made! Bradley guessed there might be an angle of about two seconds, which would make the fixed stars to be 400000 times as far from us as the sun! M. J. Cassini supposed the annual parallax of Sirius to be six seconds, from which it was calculated to be 18000 times further from us than the sun. Now, as light (like gravity) diminishes as the squares of the distances in-

crease, i. e. if a candle at *a*, Fig. 35, Plate 6, enlightens a square board, *c d*, with a given quantity of light, at twice the distance, that light is divided into four, so on each of the four parts there is but one-fourth part of the light, as on *c d*, each of the squares being of equal size. At three times the distance there is but one-ninth on each square, as on *c d*; and at four times the distance there is but one-sixteenth of the light on each square, as on *c d*, &c. &c. Light, therefore, diminishing in this proportion, it is impossible that the light of our sun should reach so far as the fixed stars, and be from them reflected back with that amazing lustre with which they shine. If then they do not shine by borrowed light, as our moon and the planets do, they must shine, as our sun does, by their own inherent light, and, by analogy, be suns themselves. But if they are suns, by the same analogy they must be destined for the same noble purpose as our sun: to give light, heat, and vegetation, to various worlds that revolve round them, but which are infinitely too remote to be perceived by us, though assisted by our greatly-improved telescopes! How much too vast for the human mind is this idea! But the idea must be carried still further: for we see every particle of our globe swarm with life and animals; and can we suppose such bodies as compose the rest of our system made for nothing but for mortals to gaze at? They turn as regularly on their axes, and perform their annual revolutions, with equal precision as our earth. Many of them have summer and winter, spring and autumn, as well as the earth; and three of these planetary worlds abound with moons to assist their light. Do not these similar attributes imply a similar use with that of the earth? and that we may conclude those worlds to be inhabited?

The analogy goes still further. We see our sun turn on his axis.

The fixed stars Algol, β Lyra, δ Cephei, η Antinoi, ο Cetí, &c.* are known to turn in like manner, by their growing periodically darker and brighter, in stated times. Must not these revolutions be for the purpose of throwing off centrifugal light to the worlds that surround those suns; causing their motions, and diffusing all-cheering light through space?

Astronomers divide the heavens into three regions—a northern and a southern hemisphere, and the zodiac. Stars of various magnitudes are seen in all these regions, and are classed into constellations of variety of figures, as men, quadrupeds, fish, &c. These figures are said to have originated with the ancient Chaldeans, or Egyptians; but some of them being found on the ruins of pagodas, and observatories in Hindostan, they seem, like most other sciences, to have sprung from the east. The Egyptians were remarkable for their hieroglyphics, and allegories. Poverty in language, always begets poetry. Where there are not words to express ideas, mankind have recourse to allusion, to allegory, and symbols. Of that description are the figures we find on ancient charts of the heavens; and which are copied on our celestial globes. The idea was grand and ingenious! The tenets and mysteries of a mythology were thus registered upon the face of the heavens; a book, eternal (to our ideas at least), and that all mankind could see. The Greeks, struck with the magnificence of the idea, displaced many of the Chaldaic con-

* Algol revolves in three days; β Lyra, in five days; δ Cephei, in six days; η Antinoi, in seven days; ο Cæti, in 331 days; Hydra, in 394 days; the bright star in the neck of the swan, in 497 days; α Hercules, sixty days. This periodical diminution of light and disappearance, with the reappearance and augmentation of light, in many of the fixed stars, is referred to spots on their surface. Some have thought it might be explained by supposing them of a discoid figure, like a plate; sometimes turning their flat, and at others their narrow and sharp side towards us. Either supposition equally connects itself with that of a rotation on their axis, to account for the effect.

stellations, and inserted much of their own fable and poetic theology: hence we find Hercules, Perseus, Castor, Pollux, &c. &c.

Many stars of remarkable magnitude have names beside the constellations of which they make a part; many of which were given by Arabian astronomers, as Aldebaran, Markab, Fomalhaut, &c. which are still retained on our globes. These constellations answer a convenient end, in the use made of them by modern astronomers; they form a contour or outline, become a kind of demarcation, by which every spot in the heavens can be called by a specific name; and by Bayer's Letters, every star capable of being seen by the naked eye has a distinct name. The largest apparent star in a constellation has the first letter of the Greek alphabet placed before it; the second in size, the second letter, &c. so that though this alphabet is repeated over and over again, yet being in different constellations the stars have each a different name. I see α in Orion, and α in the Twins; I call one Alpha Orionis, and the other Alpha Geminorum, &c. Hence, if a comet, or any strange phenomenon, appeared in the heavens, I could write to my correspondent in China, and direct him to the sight of it, as well as if I pointed it out with my finger.

Northern Constellations.

Constellations.	English Names.	Remarkable Stars.	Mag.
Ursa Minor -	Little Bear -	α Ursa Min. Polar Star	2,3
Ursa Major -	Great Bear -	α Ursa Majoris -	2
Draco - -	Dragon - -	γ Draconis - -	2
Cepheus - -	- - - -	- - - - -	
Bootes - -	Bear Driver -	Arcturus - -	1
Coma Berenices	Berenice's Hair	- - - - -	
Cor. Caroli -	Charles's Crown	- - - - -	
Coron. Borealis -	Northern Crown	α Coronæ Borealis	2
Hercules - -	Hercules - -	α Hercules - -	2,3
Cerberus - -	- - - -	- - - - -	
Lyra - -	The Lyre -	α Lyræ - -	1
Cygnus - -	The Swan -	α Cygni - -	
Vulpecula -	The Fox -	- - - - -	
Anser - -	The Goose -	- - - - -	
Lacerta - -	The Lizard -	- - - - -	
Cassiopeia -	- - - -	β Cassiopeia - -	2
Camelopardalis -	The Camelopard	- - - - -	
Serpens - -	The Serpent -	α Serpentis - -	2
Ophiuchus -	Serpentarius -	α Ophiuchi - -	2
Aquila - -	The Eagle -	Attair - - -	1
Antinous - -	- - - -	- - - - -	
Delphinus -	The Dolphin -	- - - - -	
Equulus - -	The Horse's Head	- - - - -	
Sagitta - -	The Arrow -	- - - - -	
Andromeda -	- - - -	β Andromeda -	2
Perseus - -	- - - -	β Persei. Algol -	2
Pegasus - -	The Flying Horse	γ Peg. Algenib -	2
Auriga - -	The Waggoner	Capella. Little Goat	1
Lynx - -	- - - -	- - - - -	
Leo. Minor -	The Little Lion	δ Leonis Min. -	1,3
Triangulum -	Triangle - -	- - - - -	
Musca - -	The Bee - -	- - - - -	
Taurus Poniatowski	- - - -	- - - - -	

Southern Constellations.

Constellations.	English Names.	Remarkable Stars.	Mag.
Cetus - -	The Whale -	α Ceti - -	2
Eridanus - -	The River -	Achernar -	1
Phœnix - -	- - - -	α Phœnices -	2,3
Toucan - -	- - - -	- - - -	
Orion - -	- - - -	Rigel - -	1
Monoceros -	The Unicorn -	- - - -	
Canis Minor -	Little Dog -	Procyon - -	1
Apus - -	Bird of Paradise	- - - -	
Hydra - -	Water Serpent	α Hydra - -	2
Sextans - -	Sextant - -	- - - -	
Crater - -	The Cup - -	- - - -	
Corvus - -	The Crow -	- - - -	
Centaurus -	The Centaur -	α Centauri -	1
Lepus - -	The Wolf -	- - - -	
Ara - -	The Altar -	- - - -	
Triangulum -	The Triangle -	α Trianguli -	2,3
Pavo - -	The Peacock -	α Pavonis -	2
Corona Aust. -	Southern Crown	- - - -	
Grus - -	The Crane -	α Gruis - -	2
Pisces Aust. -	Southern Fish -	Fomalhaut -	1
Lepus - -	The Hare -	- - - -	
Columba - -	Noah's Dove -	α Columba -	2
Robur Caroli -	Royal Oak -	- - - -	
Crux - -	The Cross -	α Crucis - -	1
Argo Navis -	The Ship -	Canopus - -	1
Canis Major -	Great Dog -	Sirius the Dog-star	1
Apis - -	The Bee, or Fly	- - - -	
Hirundo - -	The Swallow -	- - - -	
Chamelion -	- - - -	- - - -	
Pisces Volans -	Flying Fish -	- - - -	
Xyphias - -	The Sword-fish	- - - -	

Constellations of the Zodiac.

Constellations.	English Names.	Remarkable Stars.	Mag.
♈ Aries - - - -	the Ram - - - -	α Arietis - - - -	2
♉ Taurus - - -	the Bull - - - -	Aldebaran - - -	1
♊ Gemini - - -	the Twins - - -	Castor and Pollux -	1.1
♋ Cancer - - -	the Crab		
♌ Leo - - - - -	the Lion - - - -	Regulus - - - -	1
♍ Virgo - - - -	the Virgin - - -	Spica - - - - -	1
♎ Libra - - - -	the Scales - - -	α Libræ - - - -	2
♏ Scorpio - - -	the Scorpion - - -	Antares - - - -	1
♐ Sagittarius - -	the Archer - - -	ε Sagittarii - -	2
♑ Capricornus - -	the Goat		
♒ Aquarius - - -	Water-carrier		
♓ Pisces - - - -	the Fishes		

When we look on a celestial globe, at the symbols in the above table, and find them not to agree with the animals they are meant to represent, i. e. that the symbol ♈ Aries is forty degrees behind the ram, which it represents; Taurus the same; and so on through the twelve signs—The young astronomer would be confounded for a reason, if he were not previously acquainted with the precession of the equinoxes (see page 13). This very extraordinary effect, viz. that the sun should cross the earth's equator 50″ of a degree earlier every year, than in the preceding year, and so, that the equator shall cut the ecliptic a whole degree retrograde in the course of seventy-two years, makes it necessary to have celestial globes renewed, at least, every seventy-two years; as the longitude of the stars (in the zodiac particularly) would, at this time, be a degree wrong on a globe made seventy-two years ago, as well as a small matter wrong in declination. For longitude being estimated from the first point of Aries, to the place where a line from the moon or star would cut the ecliptic perpendicularly, and a perpendicular let fall from the moon or star on the celestial equator being the declination, it is evident, on a

bare inspection of the globe, that both the longitude and declination of the stars must be perpetually moving towards the west, or in the contrary order of the signs.

Some say that Aries is the golden fleece, fetched by Jason from Colchis, and that in memory of the Argonautic expedition, it was placed in the most-distinguished part of the heavens, where the equinoctial point was at that time; and then Aries, and its symbol ♈ were together, as well as the other twelve signs. If so, we may calculate how long it is since the Argonautic expedition took place: for if the equinoctial point has gone back forty degrees from the stars that form the constellation Aries, and each degree require seventy-two years, then 72 multiplied by 40 gives 2880 years since Jason sailed across the Black Sea, to steal the woollen manufactory, and bring it into Greece; for, I suppose, this is the plain English of that celebrated expedition.

Others make the ram and the bull emblems of the season, when sheep and cows bring forth their young. The bull Apis was worshipped by the Egyptians. The twins, *Gemini*, were originally two goats; May being the season when those animals are born, and when the sun is in that sign. *Cancer*, the crab, is an animal that creeps backward, and is symbolical of the sun's leaving the northern tropic, at the summer solstice, and drawing back towards the south. *Leo*, the lion (called the fourth sign), represents the fury and heat of the dog-days. *Virgo*, the virgin, an Egyptian peasant originally, with an ear of wheat in her hand as an emblem of harvest; for the sun is in that part of the heavens at that season. *Libra*, the balance, presides at the autumnal equinox, and aptly represents the medium, or balance, between the heat and cold,

long and short days, &c. of winter and summer. *Scorpio*, the scorpion; autumn affording the cause of disorders by the abundance of its fruits: this unhealthy season, is said to be typified by this venemous reptile spreading out his long claws, and brandishing his tail, as if triumphing in the mischief he can do, and has done. Others say, this noxious animal infests Egypt upon the subsiding of the Nile, and thence became a constellation. *Sagittarius*, the archer, represented by an arrow, denotes the season for hunting. *Capricornus*, the goat, implies the return of the sun from his southern limit, and climbing up towards the north, as the goat ascends the mountains. *Aquarius* (a figure pouring out water on the earth) denotes the wet, uncomfortable time of winter; and water being a pabulum of fishes, and winter the time when all kinds of food is scarce, *Pisces*, the two fishes tied together, give intimation of the necessary season to have them so caught.

The symbols by which those signs are represented, bear an aukward likeness to the animals themselves, or parts of them, as,

♈ Aries, the two horns of a ram.

♉ Taurus. Is it possible that the two horns, and the face of a bull, could be represented by this figure?

♊ Gemini, two similar lines may, indeed, be like twins.

♋ Cancer. I suppose this symbol is meant to convey an idea of the twisting sidewise motion of the crab.

♌ Leo. Can this be intended for the hip and tail of a lion?

♍ Virgo. What this figure has to do with a virgin, or ears of wheat, is beyond my comprehension; yet the figure is said to represent three ears of wheat.

♎ Libra. This, no doubt, is intended for a scale-beam.

♏ Scorpio. Can this be meant to represent the many feet, and the sting of the scorpion?

♐ Sagittarius. An archer must have arrows.

♑ Capricorn. Why a V and an S should represent a goat, I am neither antiquarian nor astronomer enough to make out; except, indeed, they represent his crooked horns.

♒ Aquarius. This I suppose is the waves of water.

♓ Pisces The two semi-circles are to represent two bent or struggling fishes, tied together with the stroke that crosses them.

The symbols that represent the planets are of the same character as those of the signs.

☿ Mercury. This figure is the Caducius of Mercury, i. e. should represent two serpents twisted in opposite directions round a sceptre.

♀ Venus. This figure is said to be her looking-glass.

♂ Mars. The God of War has his spear and shield united into this figure.

♃ Jupiter. Probably the thunder wielded by the god.

♄ Saturn. This symbol is meant for a sickle or scythe, for Saturn was frequently represented as time.

♅ Herschel, the initial of the discoverer's name.

Fig. 1.

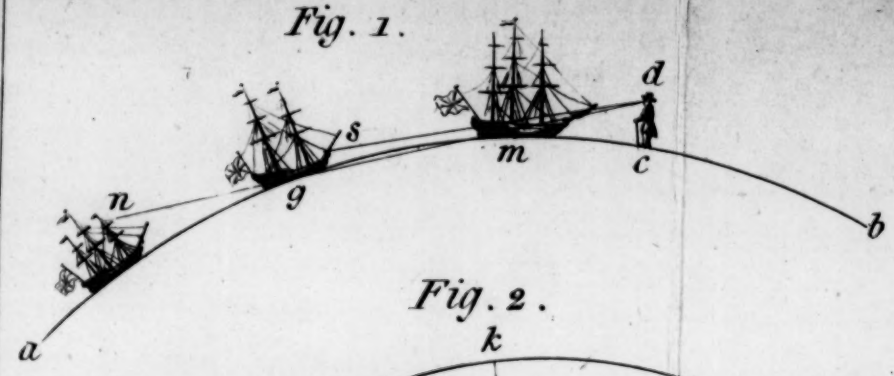


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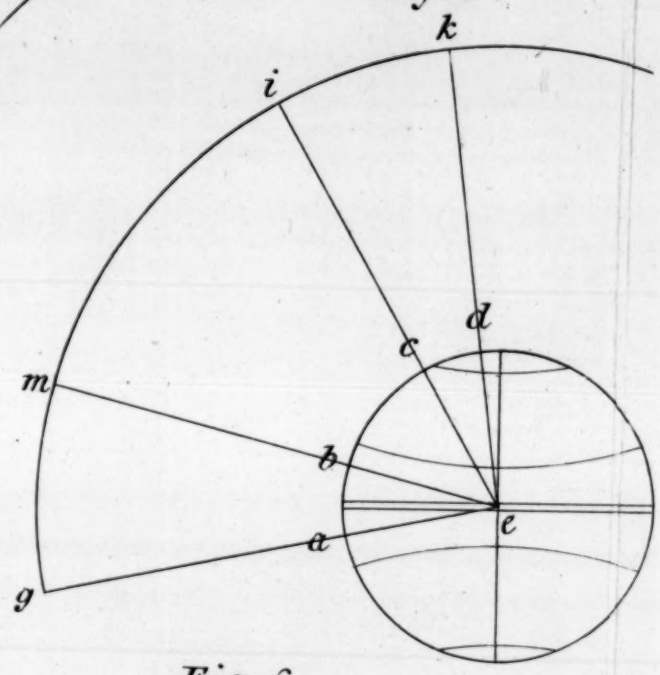


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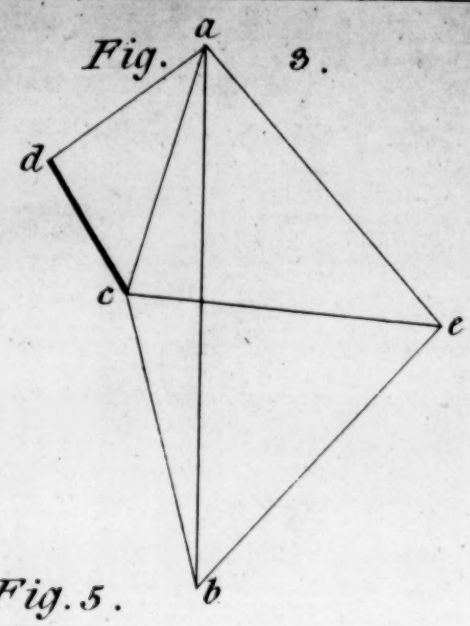


Fig. 4.



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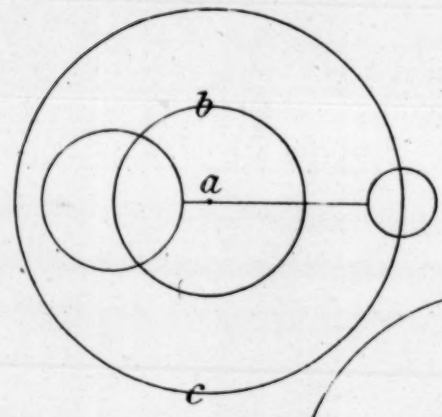


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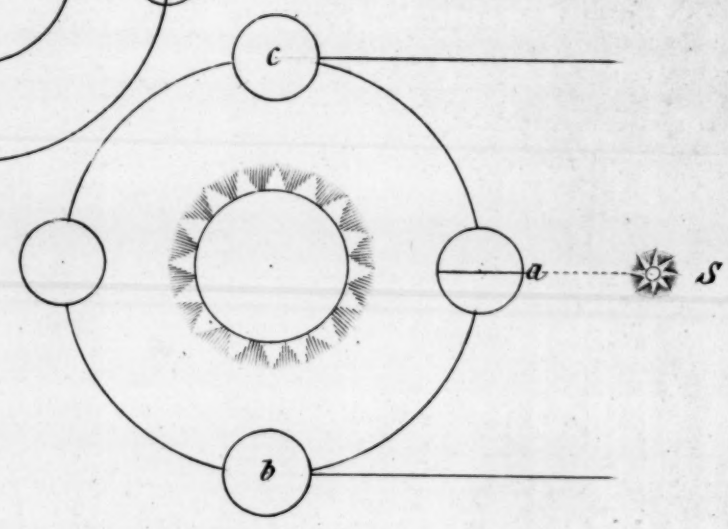


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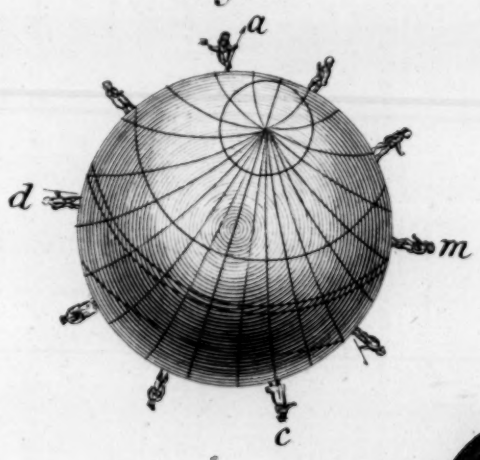
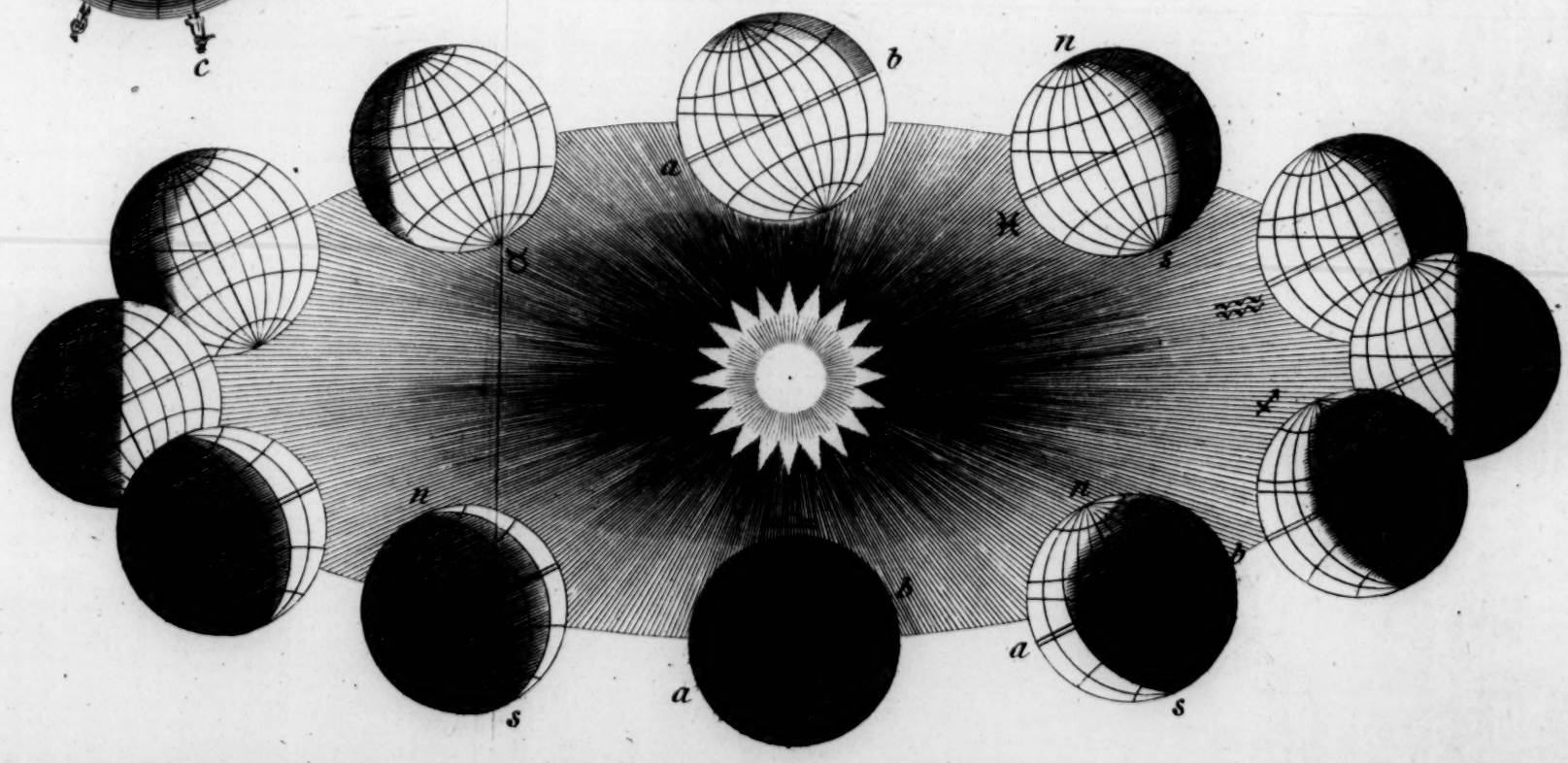


Fig. 7.



Barlow sculp

Fig. 8.

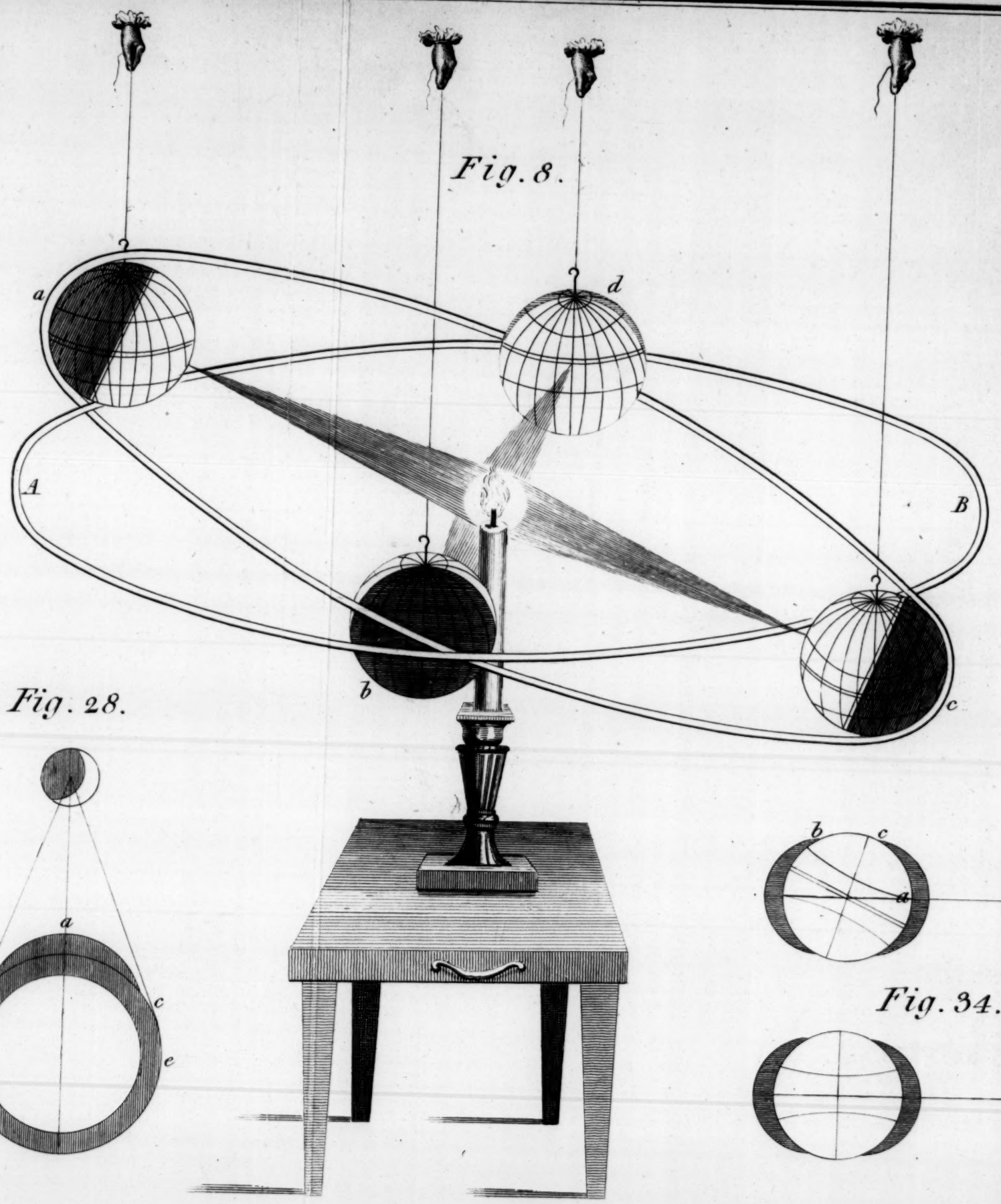
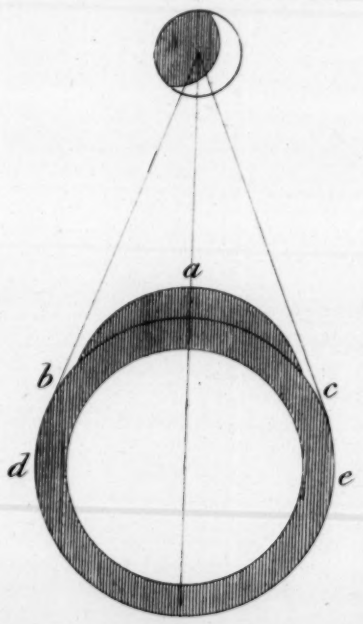


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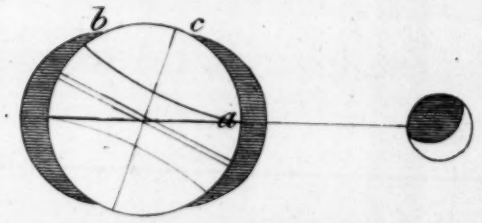


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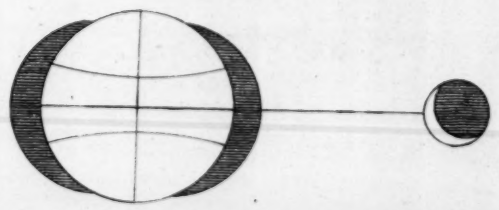
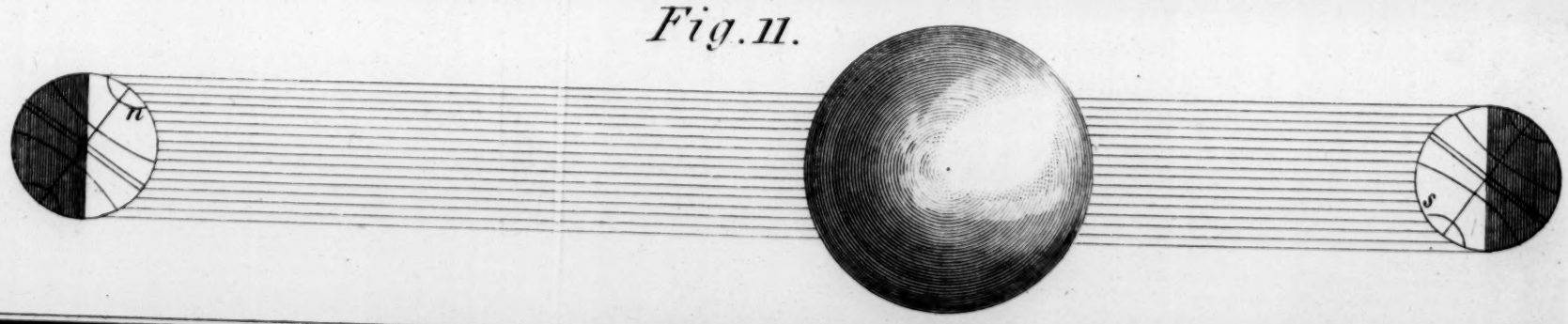


Fig. 11.



Barlow sculp.

Fig. 13.

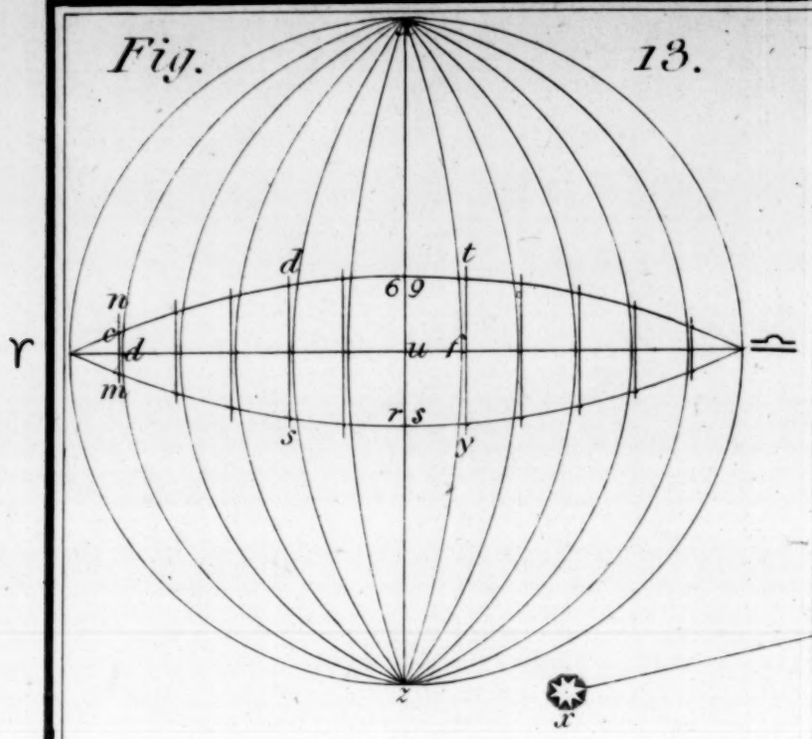


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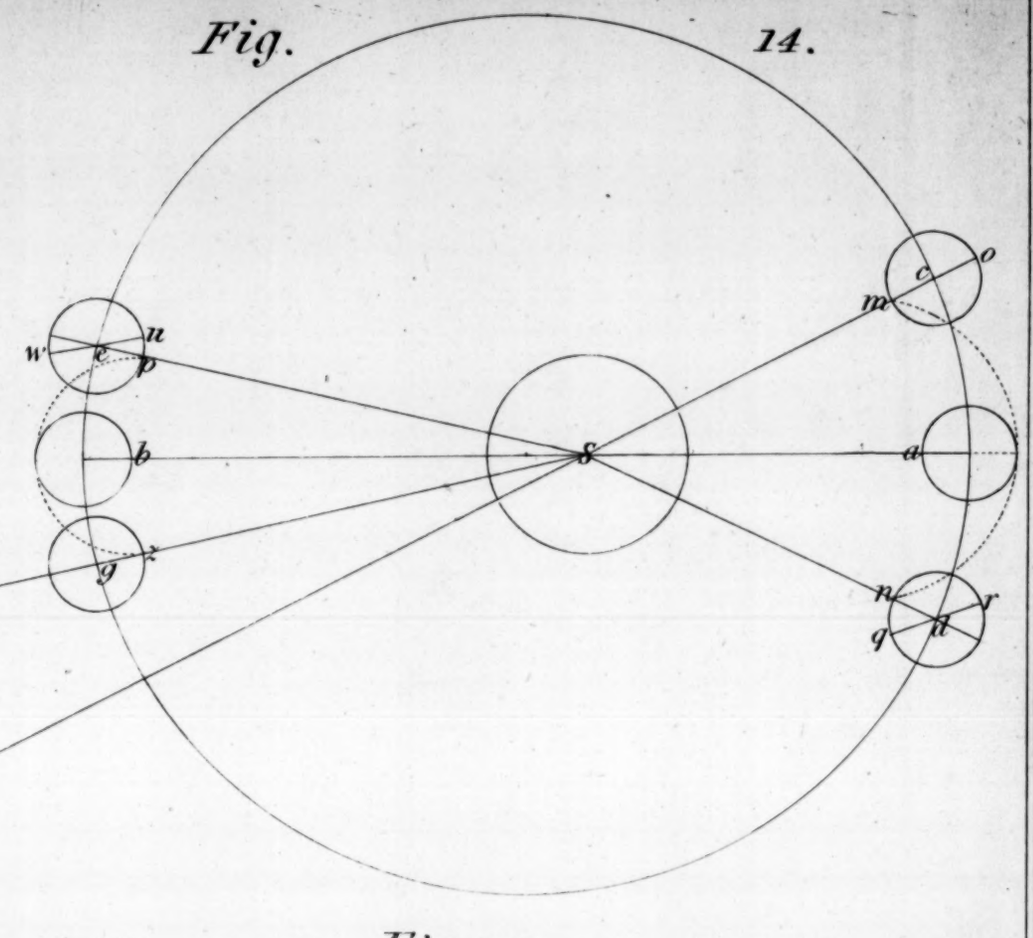


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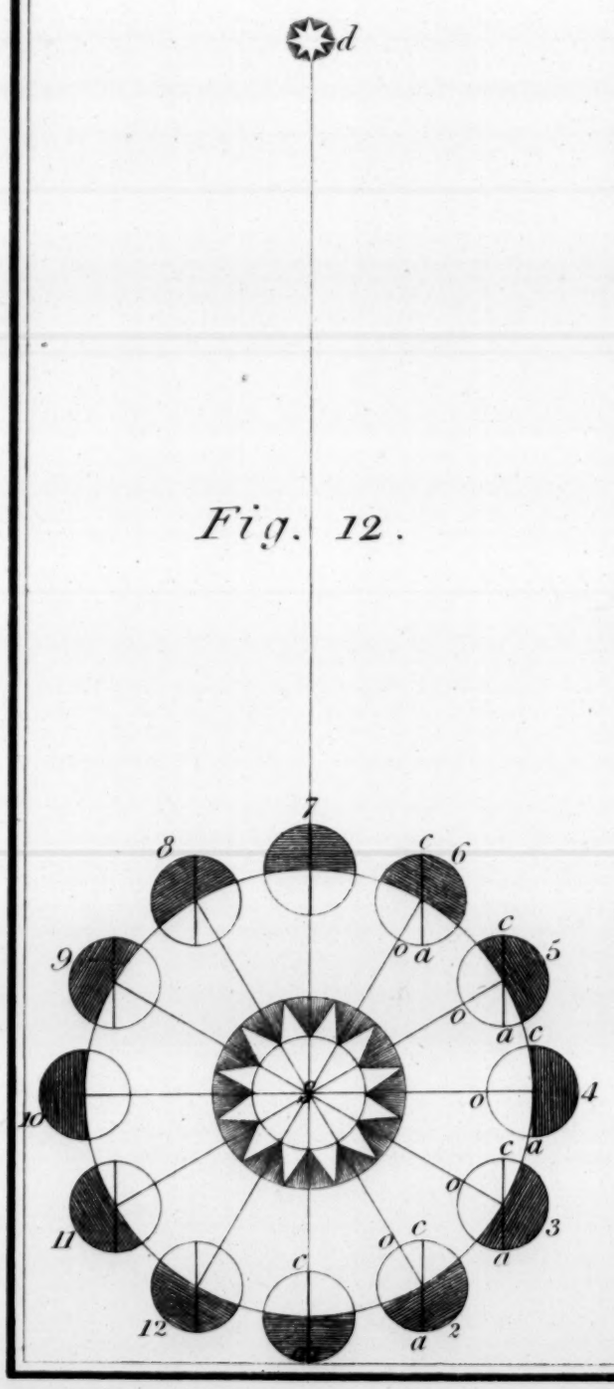
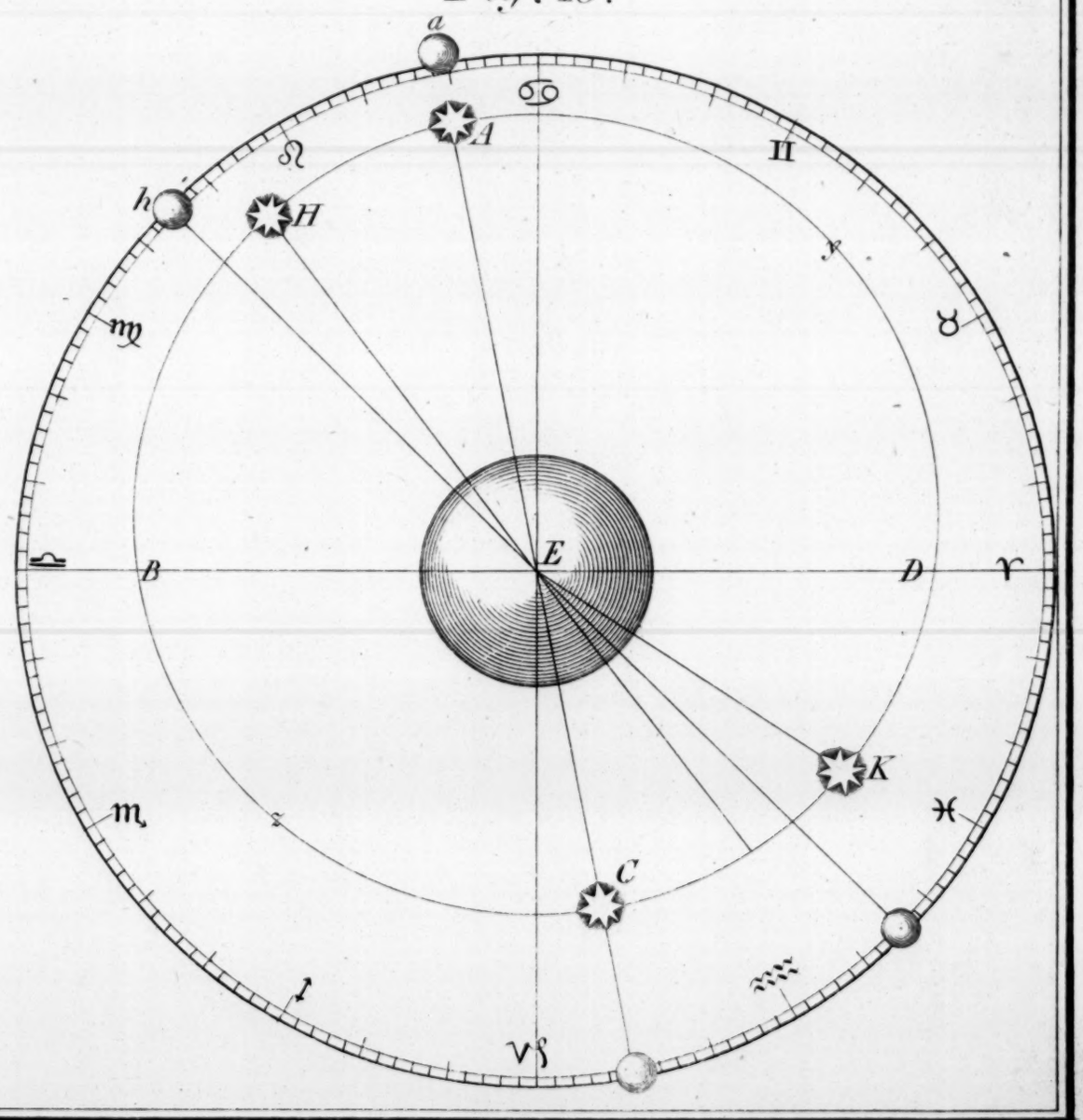


Fig. 15.



Barlow sculp.

ASTRONOMY.

Fig. 16.

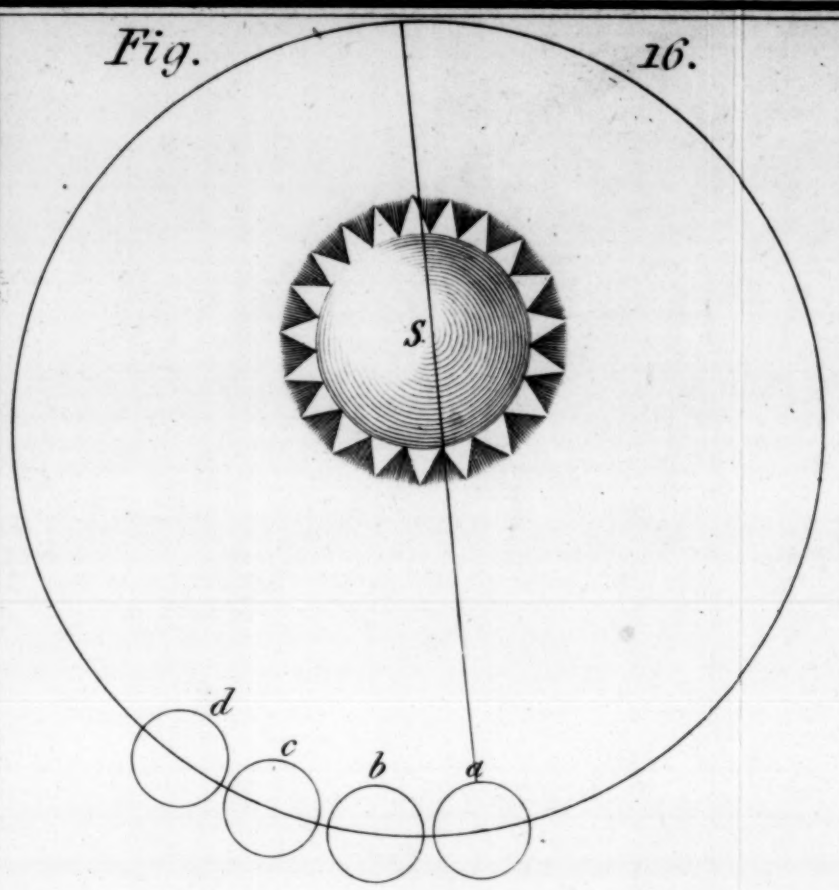


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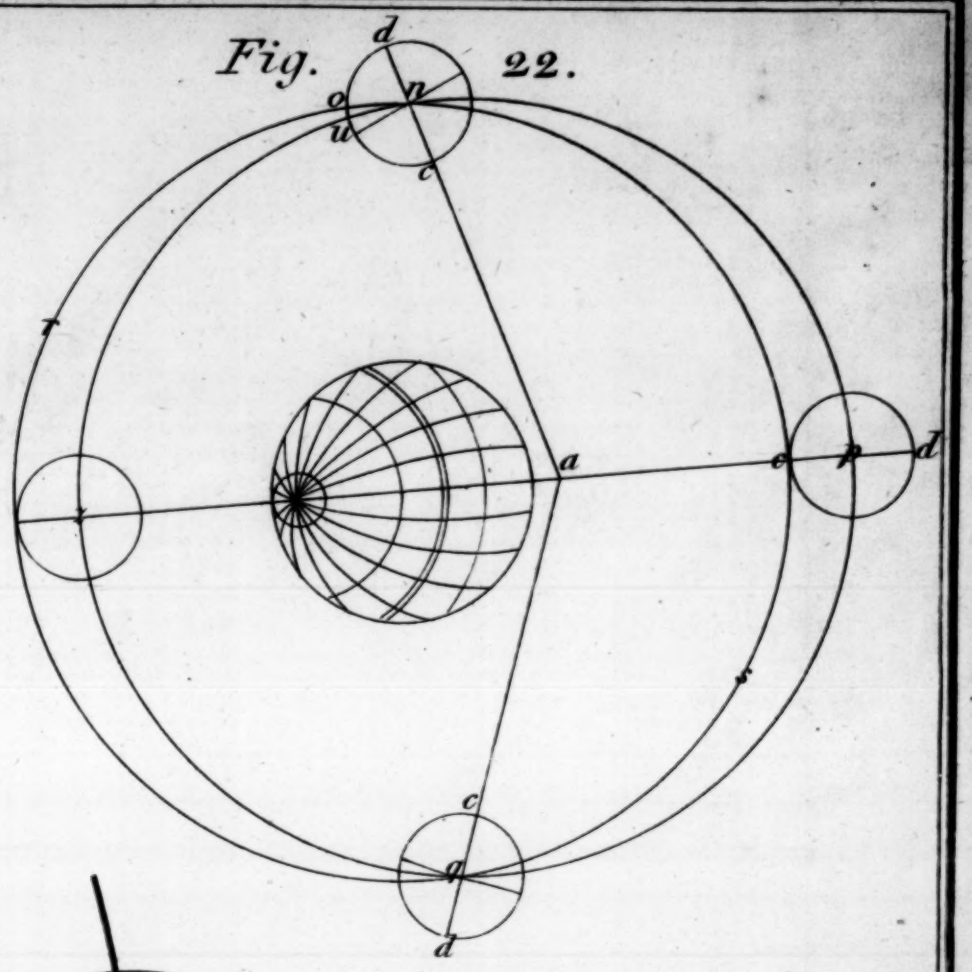


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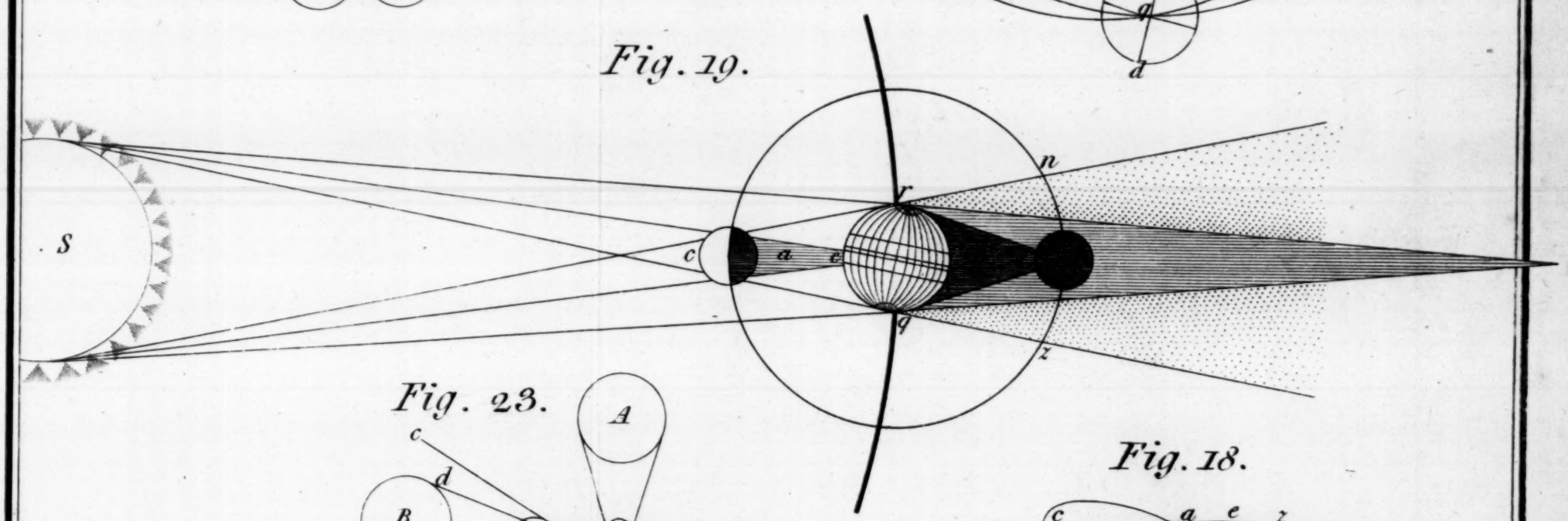


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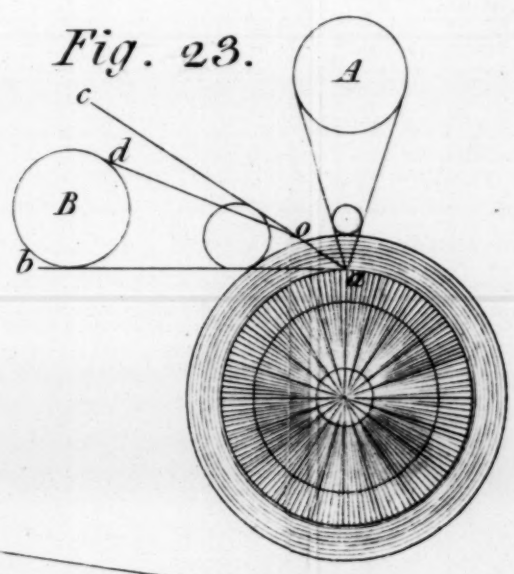


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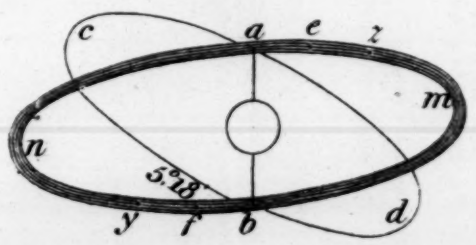
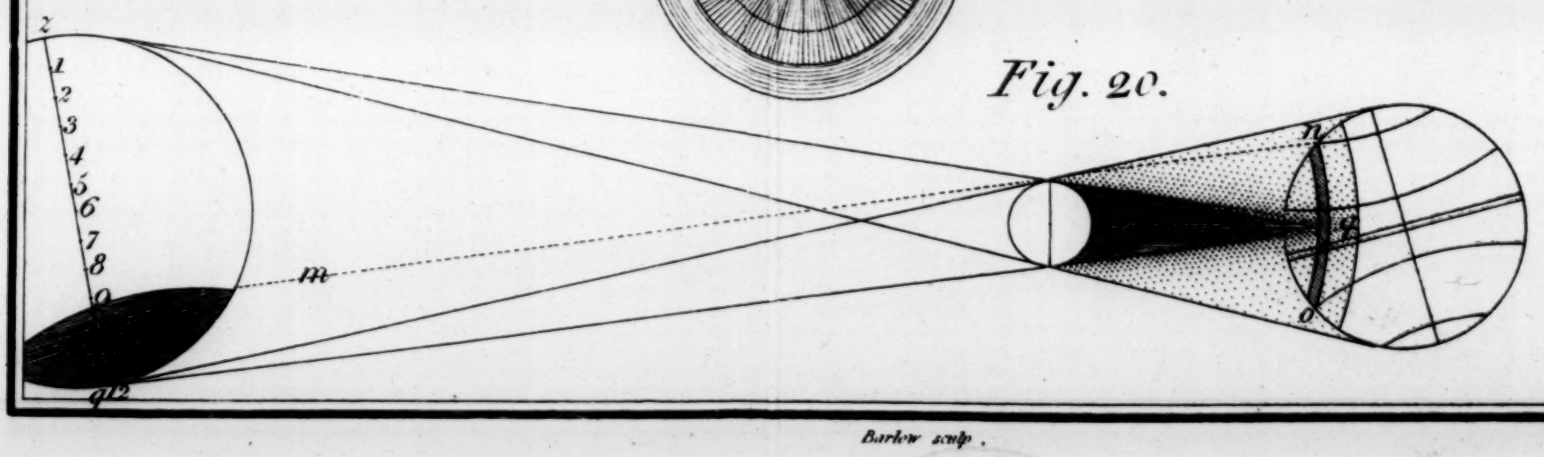


Fig. 20.



Barlow sculp.

Fig. 21.

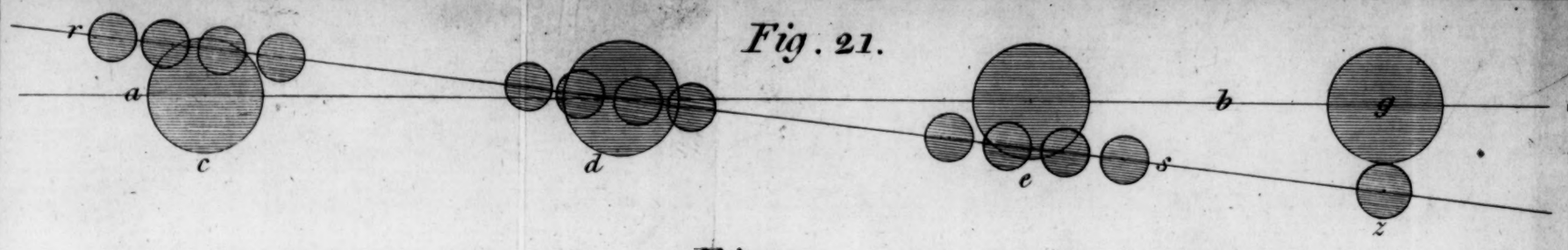


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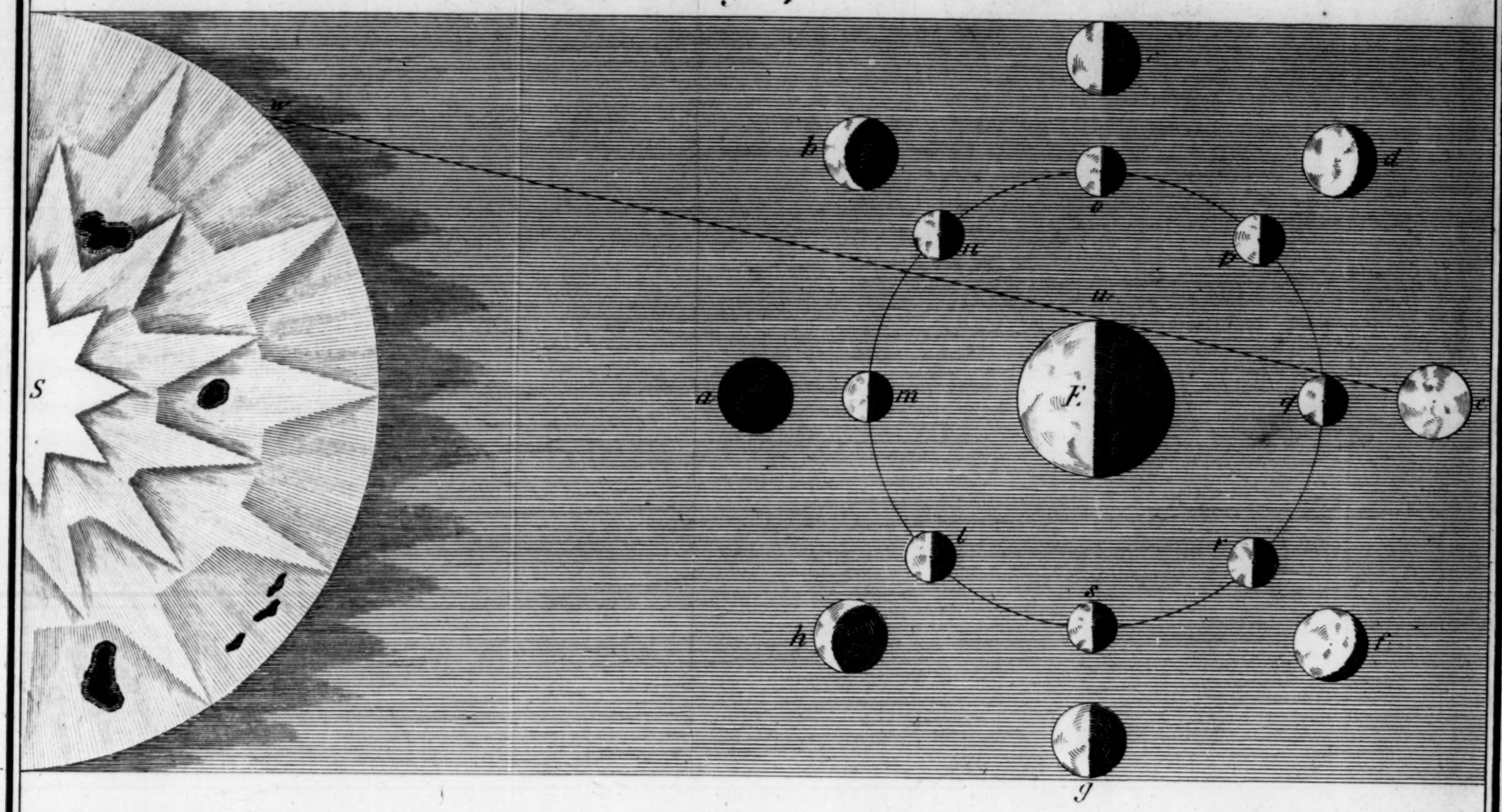
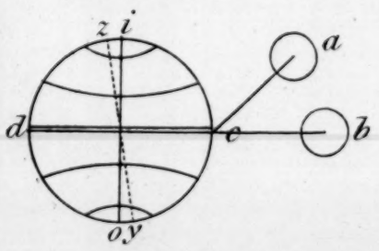


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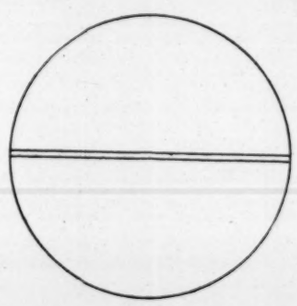


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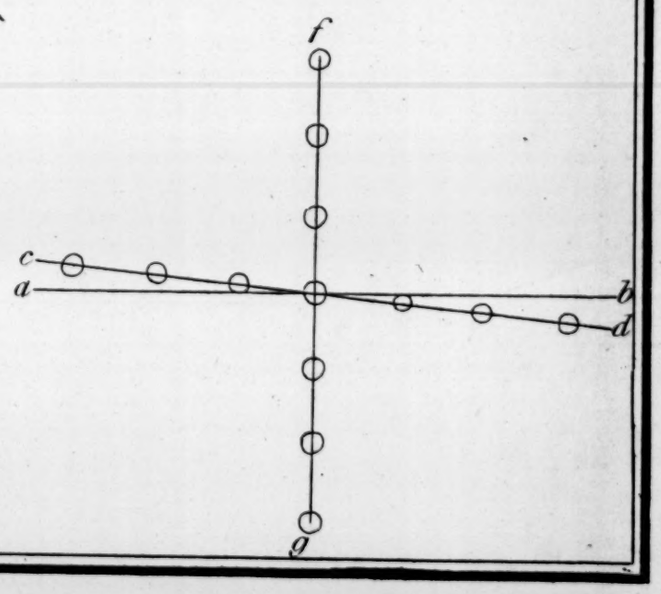
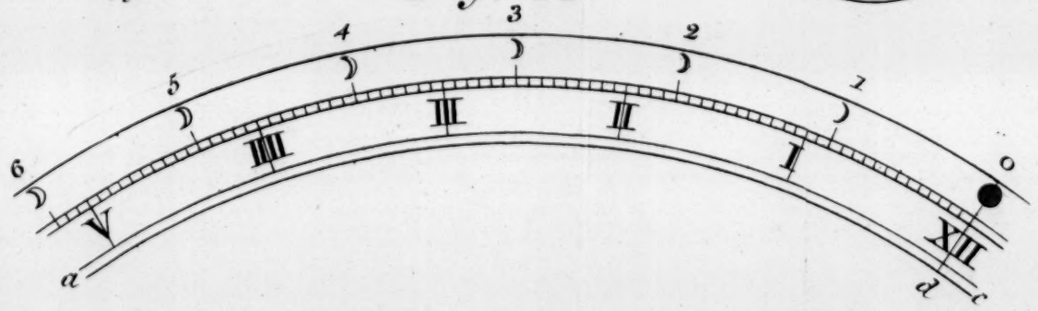


Fig. 24.



Barlow sculp.

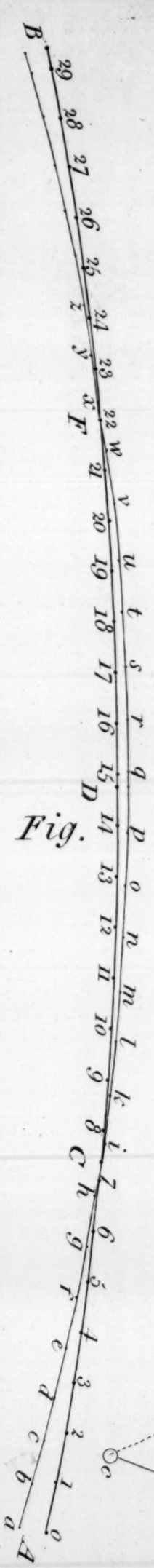


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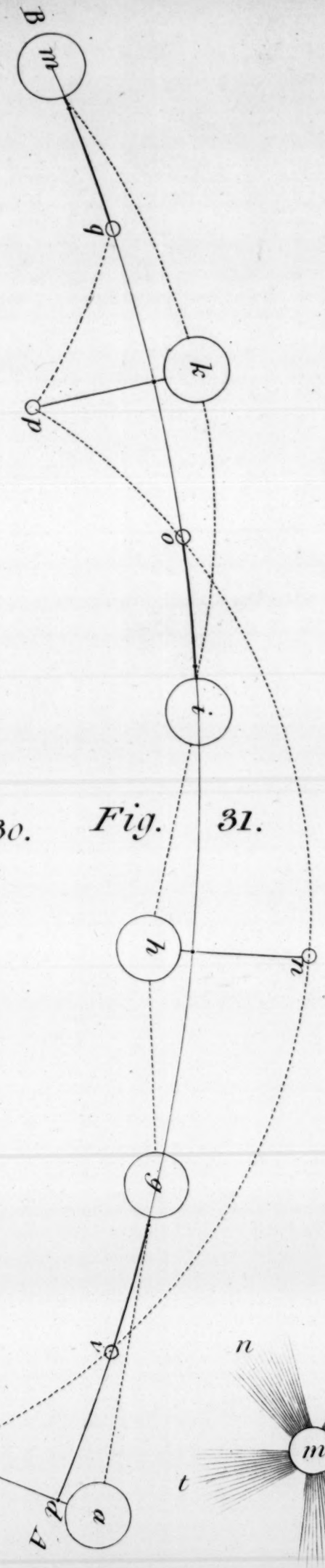


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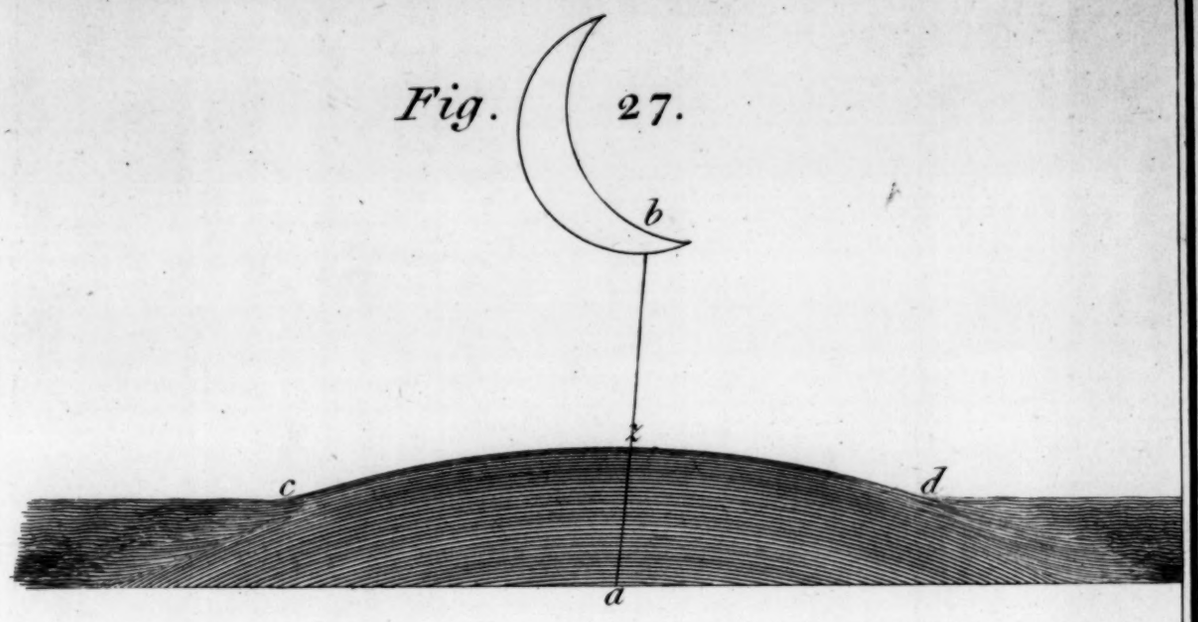
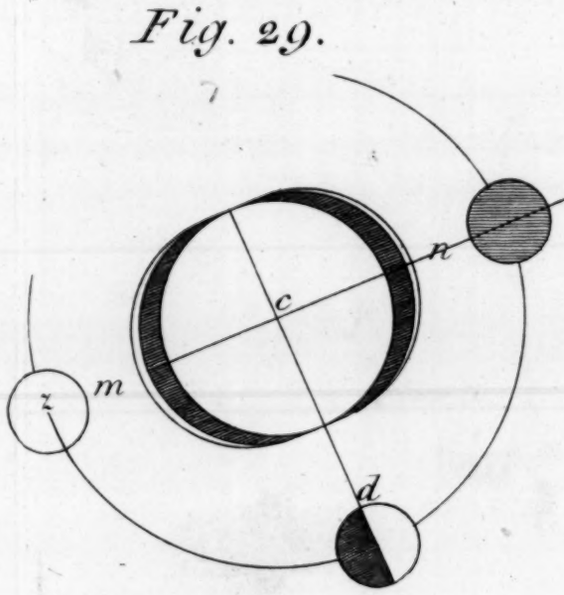


Fig. 27.

Fig. 29.



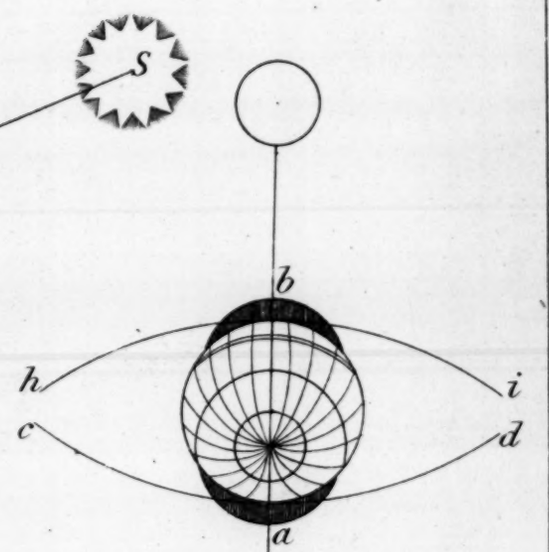
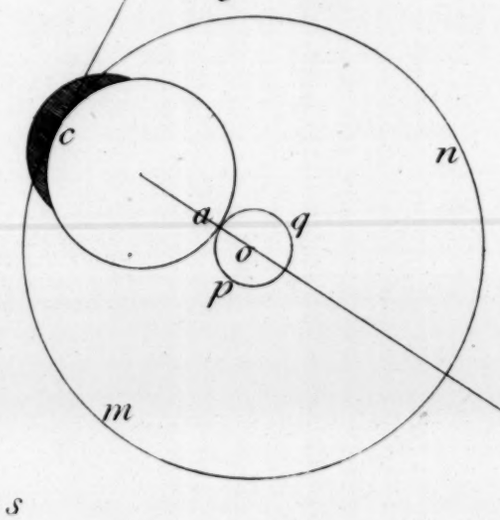


Fig. 34. page 500

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Fig. 32.



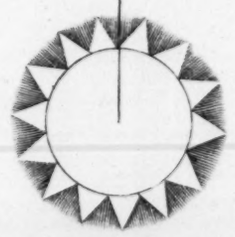


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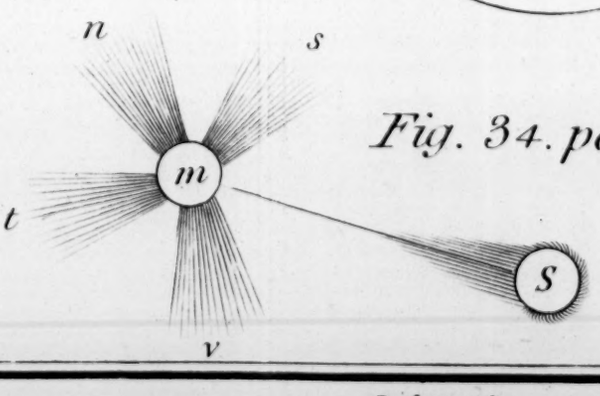
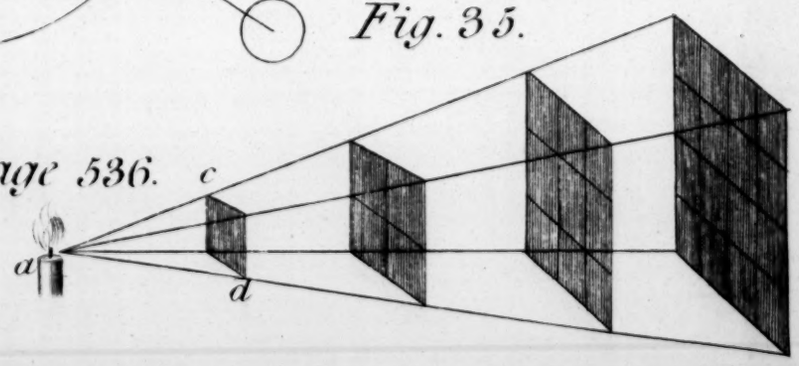


Fig. 34. page 536.



Barlow sculp

Fig. 35.

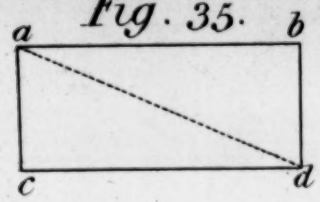


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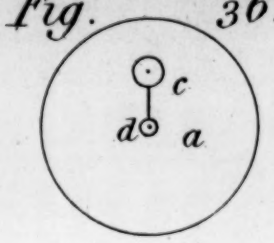


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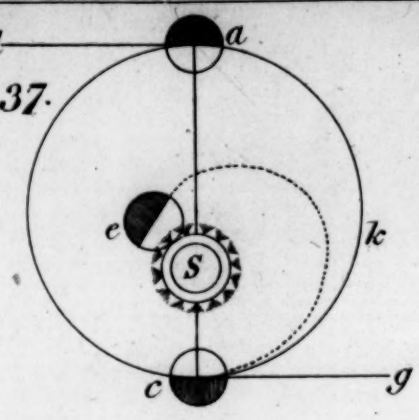
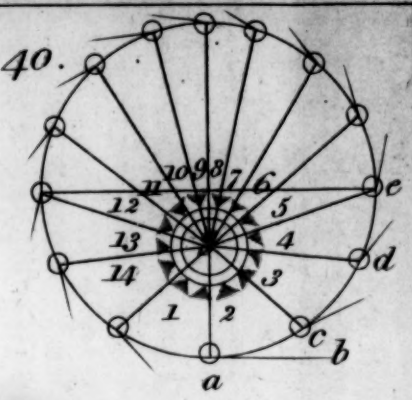


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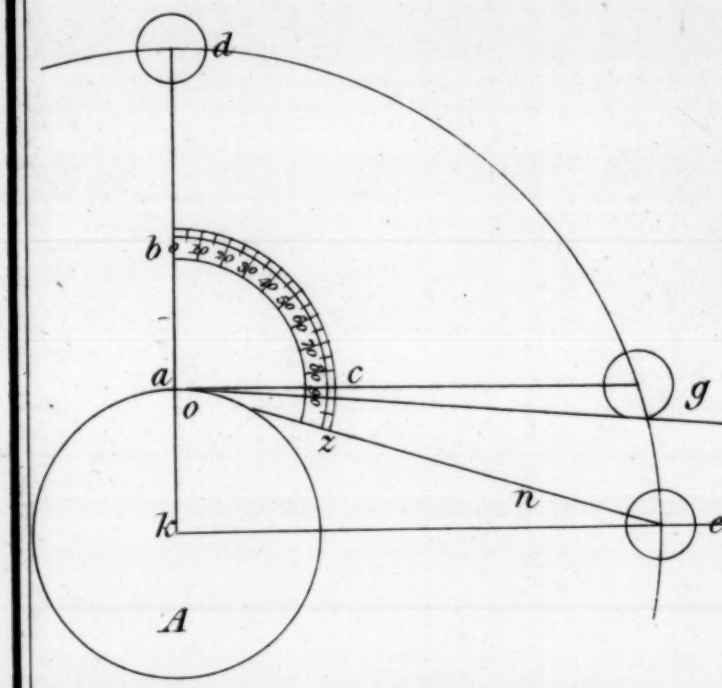


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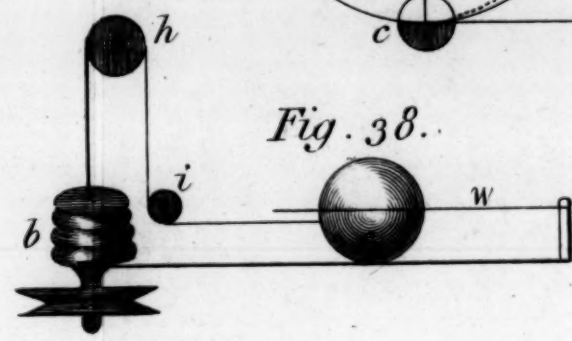


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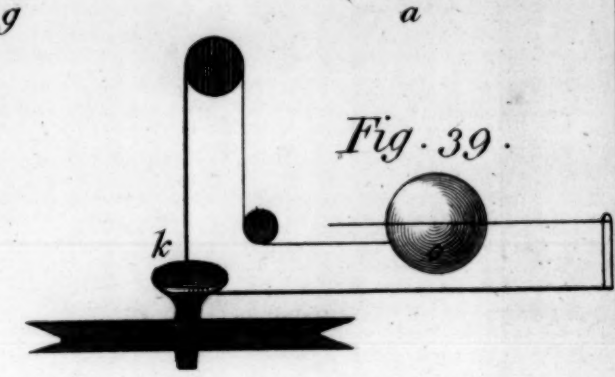


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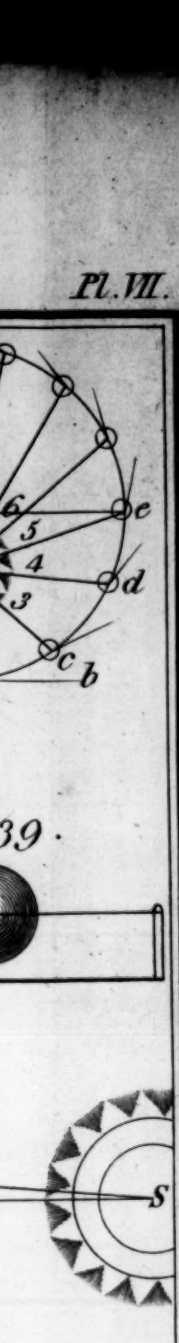


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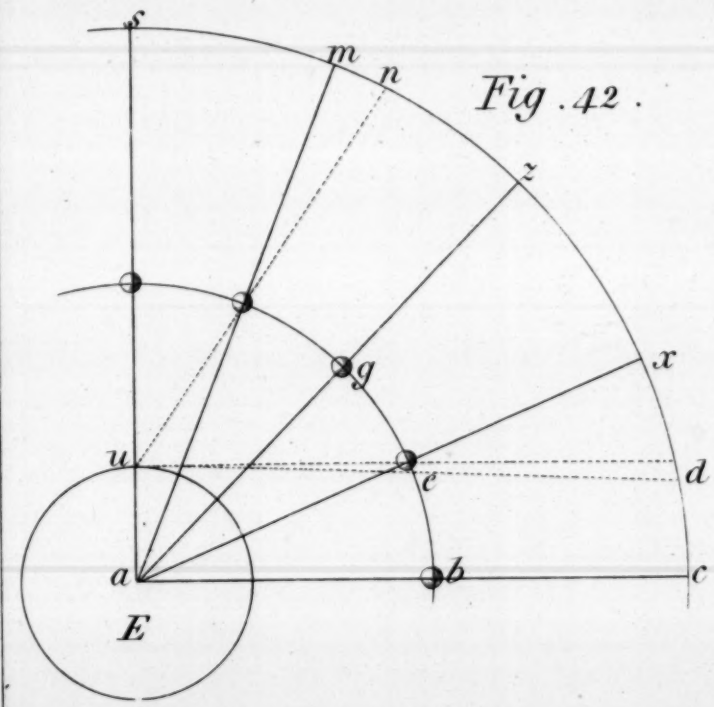


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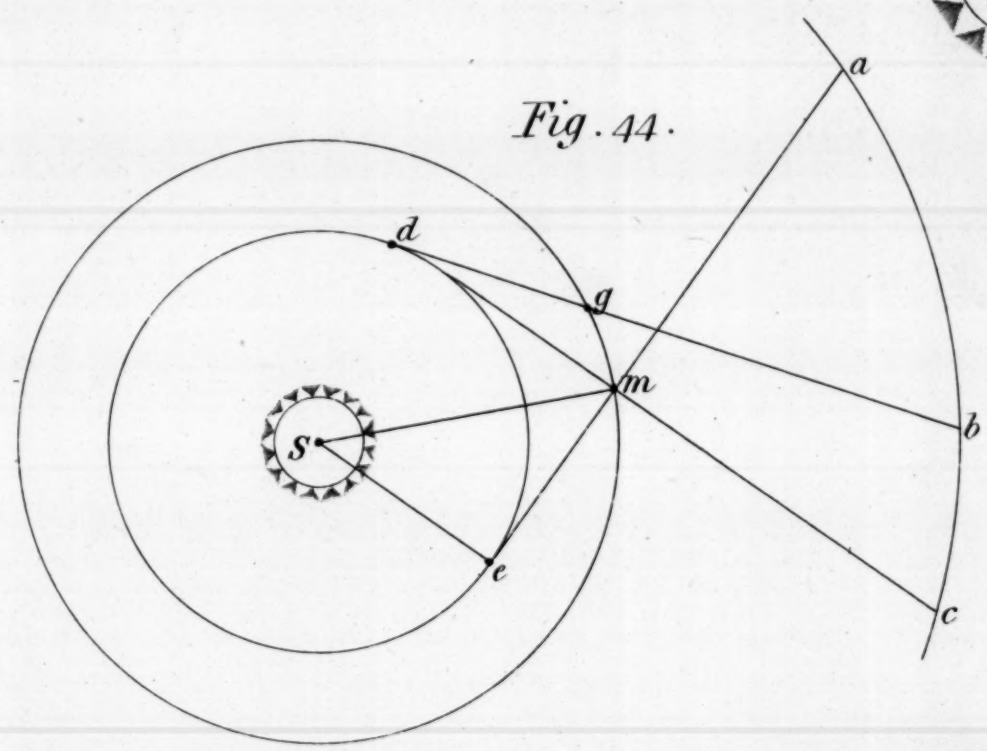
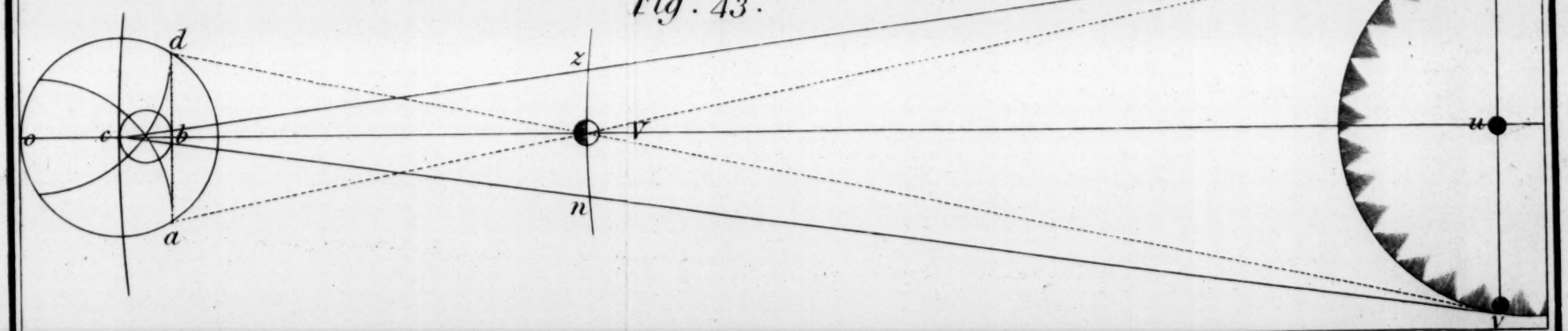


Fig. 43.



Barlow Sculp.

Fig. 45.

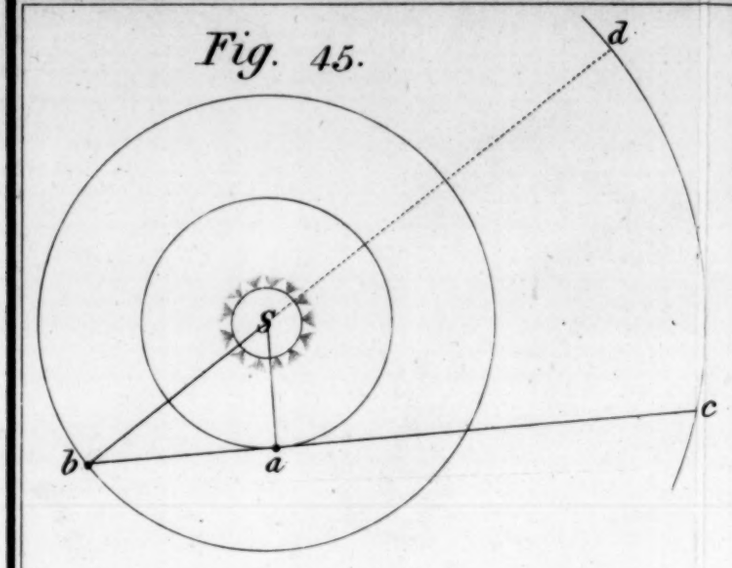


Fig. 46.

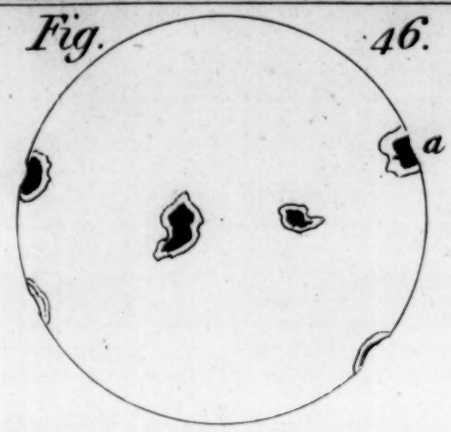


Fig. 47.

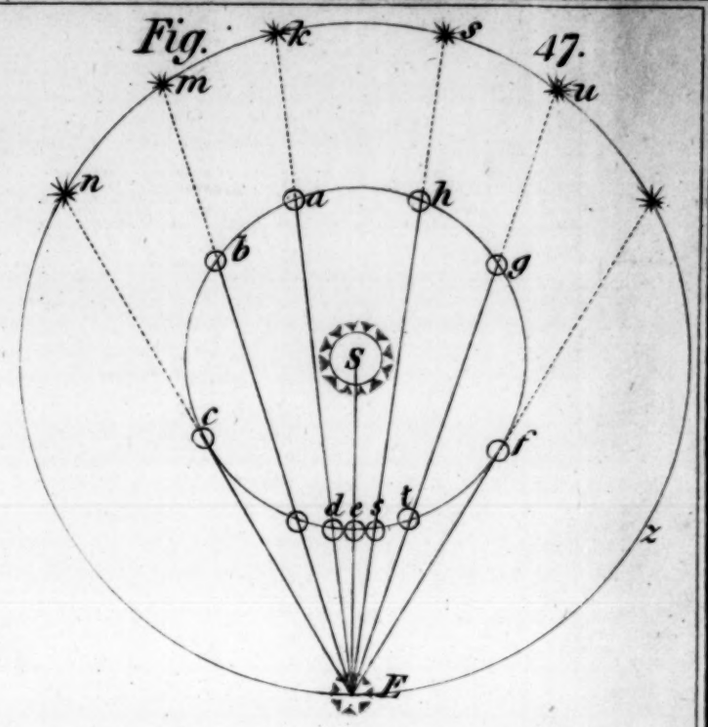


Fig. 49.



Fig. 50.

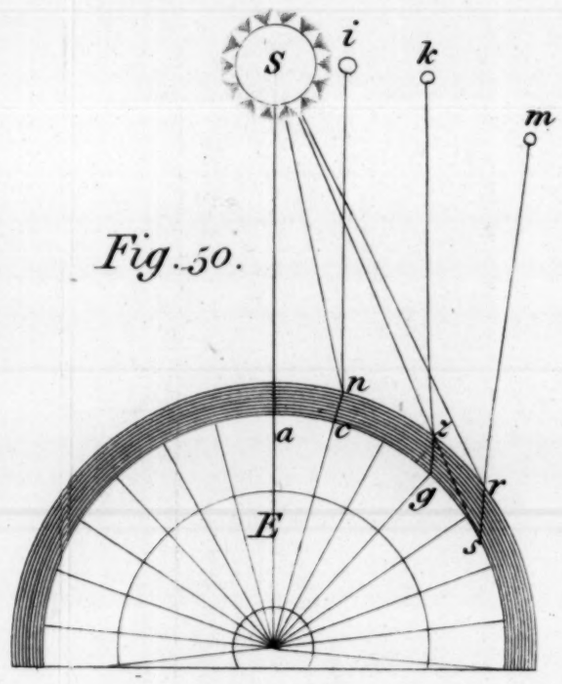


Fig. 52.

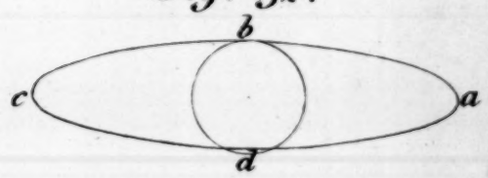


Fig. 48.

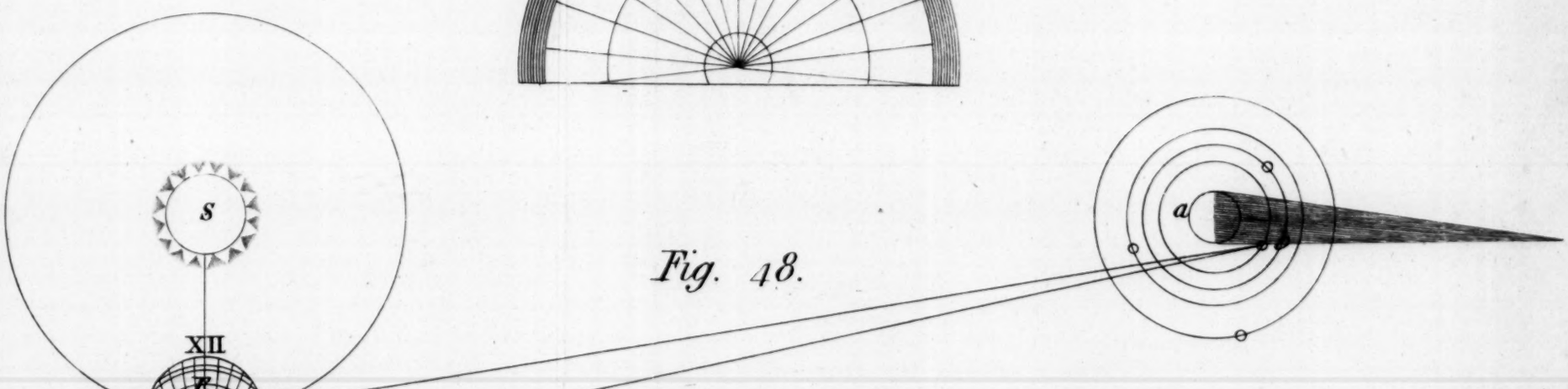
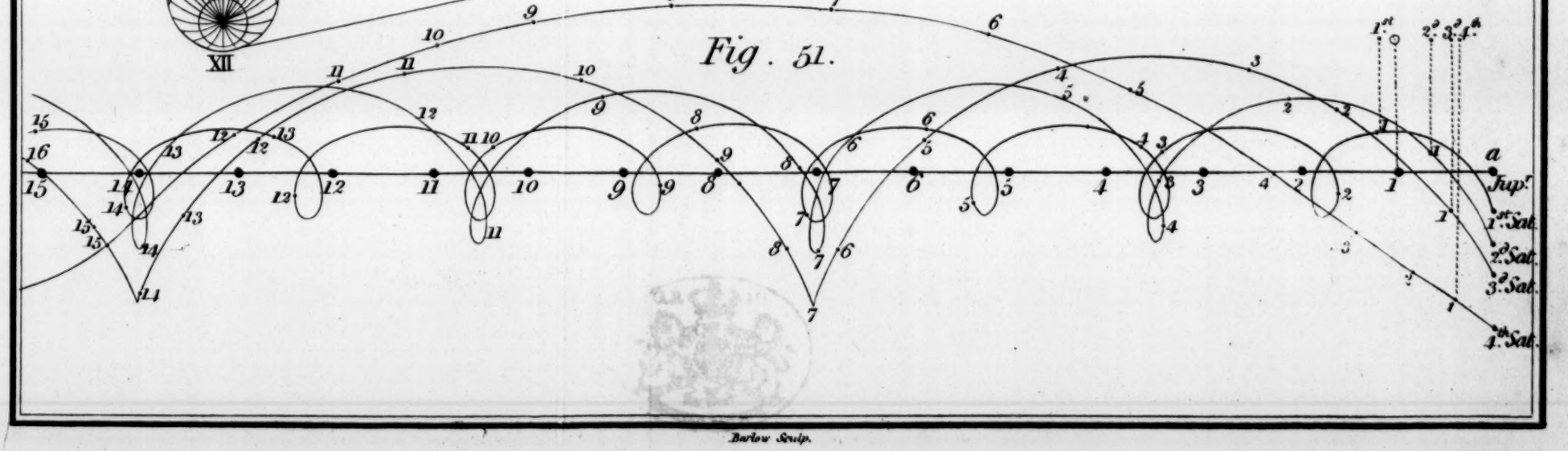


Fig. 51.



Barlow Sculp.

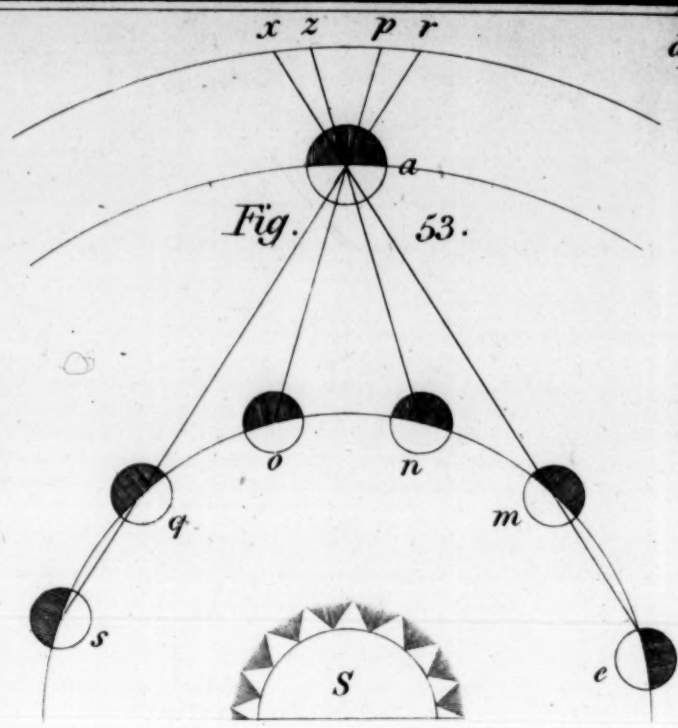


Fig. 53.

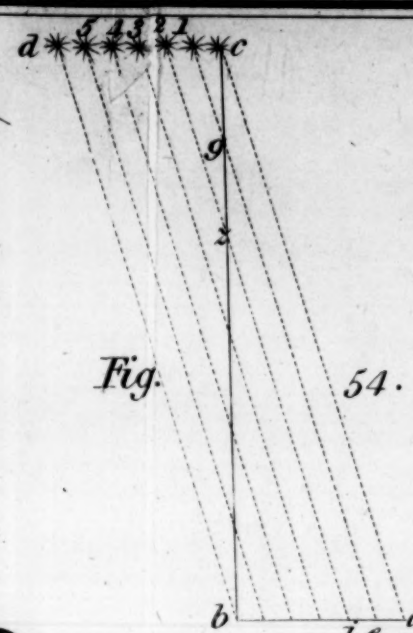


Fig. 54.

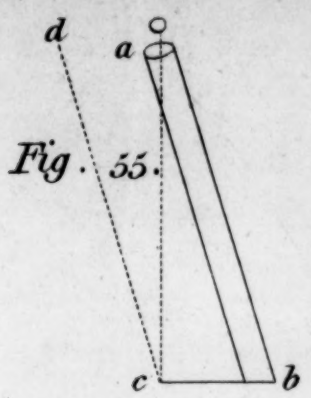


Fig. 55.

Jupiter

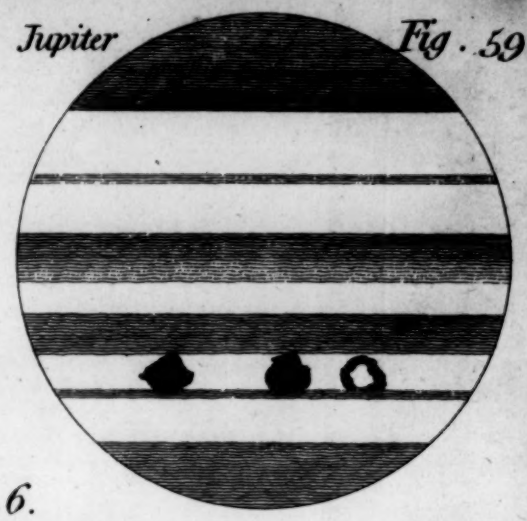


Fig. 59.

Fig. 56.

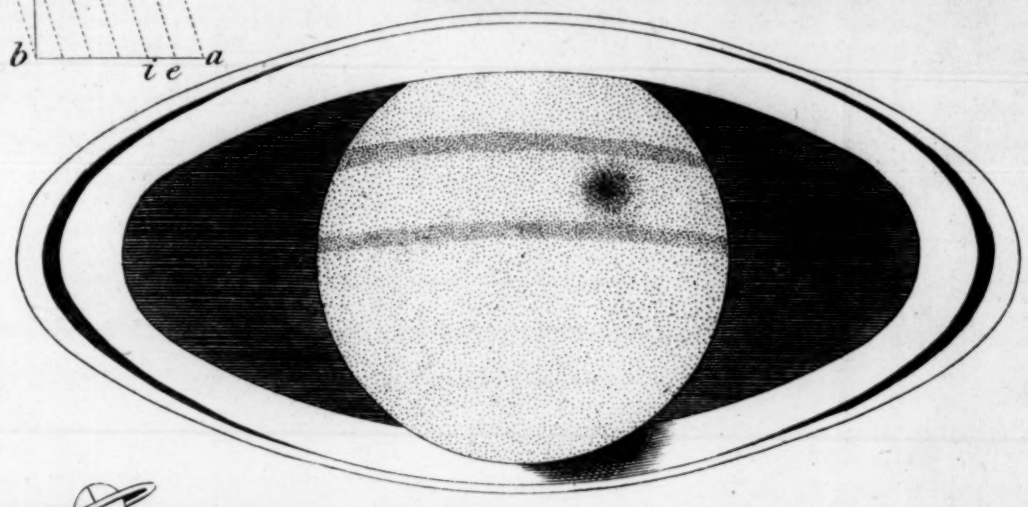


Fig. 57.



Saturn

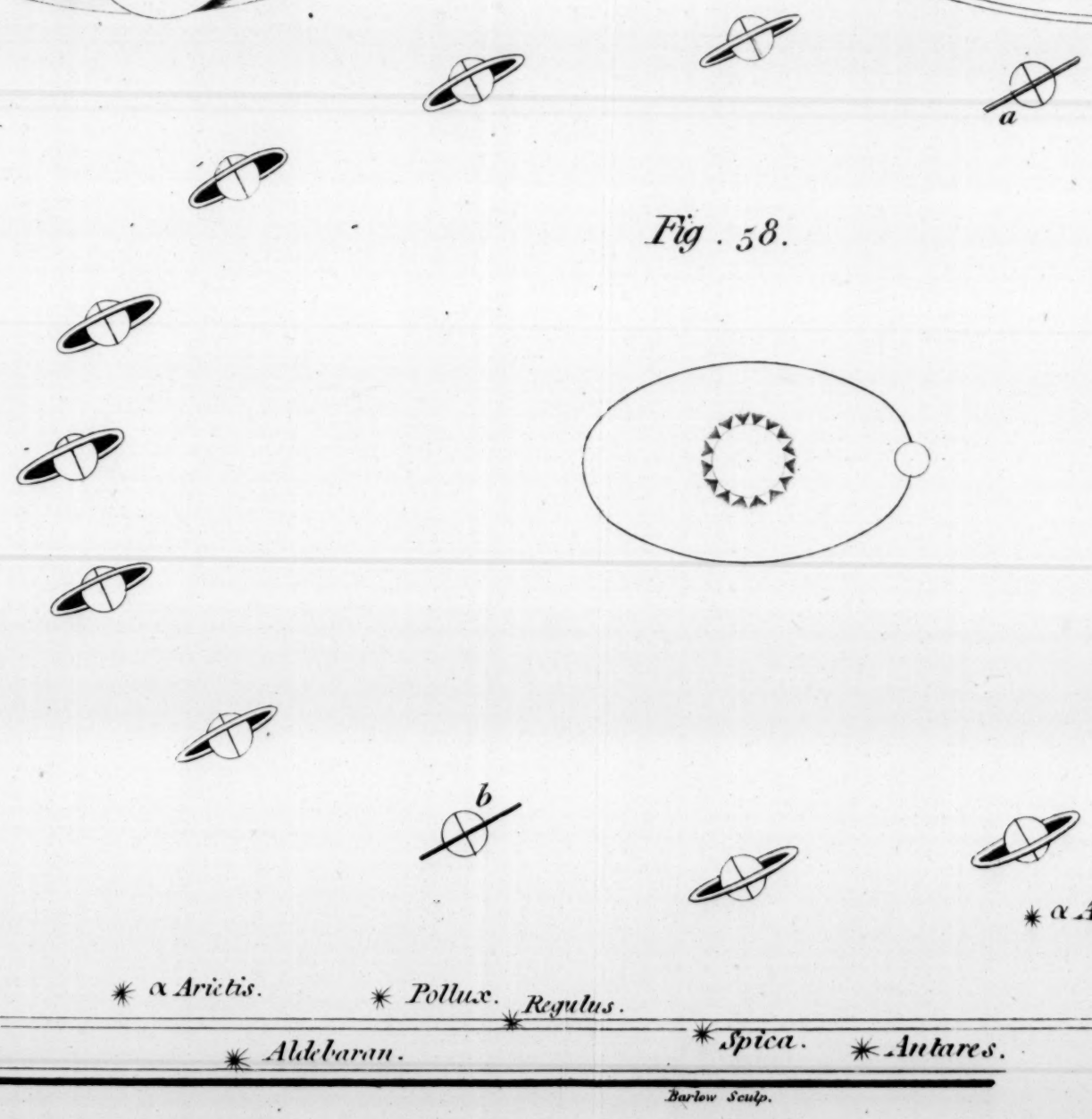


Fig. 58.

α Aquilæ.

α Pegasis.

α Arietis.

α Arietis.

Pollux.

Regulus.

Spica.

Antares.

Aldebaran.

Fomalhaut.

Barlow Sculp.

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